Experimental Investigation on Physio-Mechanical and Micro-Structural Properties of High Volume Fly Ash Concrete Incorporating Molasses as an Admixture

Kumera Daka Abajofe

A Thesis Submitted to the Department of Civil Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements of Masters of Science in Civil Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

October, 2023

Adama, Ethiopia

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DECLARATION

I hereby declared that this master thesis entitled **“Experimental Investigation on Physio-Mechanical and Micro-Structural Properties of High Volume Fly Ash Concrete Incorporating Molasses as an Admixture "** is my original work. That is, it has not been submitted to any university for similar purposes. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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Name of Student	Signature	Date

APPROVAL PAGE

I, the major advisor of this thesis entitled **"Experimental Investigation on Physio-Mechanical and Micro-Structural Properties of High Volume Fly Ash Concrete Incorporating Molasses as an Admixture"** and developed by Kumera Daka, hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Meseret Getnet, Ph.D.	______________________________	__________________
Major Advisor	Signature	Date

APPROVAL OF BOARD REVIEWERS

We, the undersigned members of the Board of Examiners of the thesis open by Kumera Daka, have read and evaluated the thesis entitled "**Experimental Investigation on Physio-Mechanical and Micro-Structural Properties of High Volume Fly Ash Concrete Incorporating Molasses as an Admixture** "and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirements of the degree of Masters of Science in Civil Engineering.

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LIST OF ACRONYMS

Acronyms	Full Name	Acronyms	Full Name
ACI	American Concrete Institute	HVFAC	High Volume Fly Ash Concrete
AEC	Air entraining Cement	IS	International Standard
Asg	Apparent Specific Gravity	LOI	Loss of Ignition
ASTM	American Society for Testing and Materials	MJ	Mega Joule
BFS	Blast Furnace Slag	MPa	Mega Pascal
Bsg	Bulk Specific Gravity	OPC	Ordinary Portland Cement
CA	Coarse Aggregate	PC	Portland Cement
CI	Construction Industry	PCC	Portland Cement Concrete
CO_2EC	Carbon dioxide Emission Coefficient	pH	Potential of Hydrogen
DEF	Delayed Ettringite Formation	SCM	Supplementary Cementitious Material
EE	Embodied Energy	SEM	Scanning Electron Microscope
EEC	Embodied Energy Coefficient	SSA	Specific Surface Area
FA	Fly Ash	SSD	Saturated Surface Dry
FM	Fineness Modulus	UWCA	Unit Weight of Coarse Aggregate
GGBFS	Ground Granulated Blast Furnas Slag	UWFA	Unit Weight of Fine Aggregate
GHG	Green House Gas	XRD	X-Ray Diffraction

LIST OF CHEMICAL FORMULAS

Formulas	Name of chemical compounds	Formulas	Name of chemical compounds
Al_2O_3	Aluminum Oxide	C_4AF	Tetracalcium Alumino Ferrite
CaO	Calcium Oxide	C-S-H	Calcium Silica Hydrate
$CaCO_3$	Calcium Carbonate	CH	Calcium Hydroxide
Ca_3SiO_5	Alite	CO_2	Carbon Dioxide
Ca_2SiO_5	Belite	Fe_2O_3	Iron Oxide
Ca_2AlFeO_5	Ferrite	K_2O	Potassium Oxide
$Ca_3Al_{12}O_6$	Almunite	MgO	Magnesium Oxide
C_2S	Dicalcium Silicate	Na_2O	Sodium Oxide
C_3S	Tricalcium Silicate	SiO_2	Silicon Oxide
C_3A	Tricalcium Almunite	SO_3	Sulfur Trioxide

ABSTRACT

The drive to mitigate the environmental impact of concrete production has spurred the exploration of waste materials as partial replacements for cement. A notable candidate is fly ash (FA). Despite the broad based research carried out across the globe in utilizing FA as a cement replacement material in concrete, the level of replacement is still limited to a maximum of 30% of cement by mass with significant quantities of FA still not utilized globally. To tackle this challenge and enhance concrete performance, the concept of High Volume Fly Ash Concrete (HVFAC) has emerged, allowing for the incorporation of up to 60% FA. Addressing both environmental concerns and performance optimization, this study investigates the integration of sugarcane molasses as an admixture, aiming to refine the formulation and application of HVFAC. Hence, in the current study, the workability, compressive strength, water absorption, microstructure, and cost and environmental aspects of C-30 HVFA concrete blended with sugarcane molasses were investigated. To this aim, ten (10) different mixes having cement replaced with 0%, 40%, 50% and 60% of FA together with varying dosage of molasses (0%, 0.1%, 0.15%, and 0.2% by mass of cement) for each percent replacement were examined. The test results indicated that with the addition of FA and molasses, the normal consistency of the mix get reduced and the initial and final setting times were also prolonged for all mix scenarios. Furthermore, it was observed that a fresh concrete mix containing HVFA and Cane Molasses was more workable than conventional concrete .The compressive strength test results of all concrete specimens showed significant strength reduction at 7-day and 28-day age against the conventional concrete. However, there was significant increase in strength from 28 to 56 days which peaks 23.13% for 60% FA and 0.2% molasses dosage. The water absorption values were observed to increase linearly with increase in FA content and molasses dosages at 28 days curing. However, water absorption of concrete linearly decreased as curing ages increased from 28 days to 56 (from 7.6% to 5.8%). Consequently, at 56 days, compared to conventional concrete, the highest reduction in water absorption is 23.68% which was obtained at a mix containing 60% FA and 0.2% molasses. Besides, *the microstructures were enhanced because of the substitution of 60% FA and 0.2% molasses. Moreover, the mix containing 60% FA and 40% cement was shown to reduce the consumption of non-renewable materials, energy consumption, CO_2 emissions, and the cost incurred for cement by 16.64%, 44.20%, 58.58% and 41.97% respectively per m^3 of concrete production.*

Keywords: Cement, Concrete, FA, HVFA, Molasses, Compressive Strength

CHAPTER ONE
INTRODUCTION

1.1.General Background

After water, concrete is the second most used construction material on this planet with an annual global consumption rate of approximately 25 x 10^9 metric tons. With the rapid growth of developing countries, the need for concrete as a building material is increasing exponentially (Amran et al. 2020; Bhat et al. 2019; Bhide et al. 2017). The demand for concrete continues to increase due to increasing population growth and development. Cement is an essential component of concrete which is commonly used as building material worldwide. The growing demand in cement for construction has led to an increase in global cement production which reached 3.99 billion tons in 2018. However, it is well known that the production of Ordinary Portland Cement (OPC) not only consumes significant amount of natural resources and energy but also releases substantial quantity of carbon dioxide to the atmosphere. The global cement industry contributes around 2.8 billion tons of the greenhouse gas (GHG) emissions annually, or about 7-8% of the total man-made GHG emissions to the earth's atmosphere(Herath et al. 2020; Vora and Dave 2013; Zin et al. 2021). Therefore, serious environmental concerns have been raised on the production of OPC in recent times. Consequently, researchers are making efforts to replace the traditional OPC with environment friendly material with properties like OPC (Waqas et al. 2021). It is thus very essential to find alternatives to make environment friendly concrete.

Apart from GHG emissions, as per the evidence revealed in Waqas et al. 2021 study, there has been significant increase in the generation of by-products and waste materials from industries, such as fly ash (FA), molten slag (SG), silica powders, lime stone dust, and ceramic wastes. For example, FA is a fine powder that is a by-product of burning pulverized coal in electric generation power plants. However, in most of the cases, the end product of FA is a waste material that is dumped into landfill sites because utilization rate of FA in most of the developing countries is not 100%. This has become a challenging task for the environmentalists and researchers to dispose of or manage these wastes and develop alternatives to traditional OPC. Approximately 544 million tons of FA are generated annually worldwide, 80% of which is disposed of in landfills. Thus, using FA as a replacement for cement has turned out to be popular in construction industries around the world because of its strong properties and crucial role in decreasing the volume of pollutants and CO_2 produced by cement production (Amran et al. 2020). The usual popular approach is to develop better and viable solutions that can utilize these products to create binder materials like OPC. This will help to resolve the issues associated with the management of these products, preserving the natural resources and simultaneously reducing the global warming effects.

Due to their good performance and environmental friendliness, FA-based construction materials have great potential as alternatives to OPC. FA is a waste material from the point of view of the power generation. However, because of the good performance and economic and environmental benefits of FA in concrete, the demand has grown steadily (Kim et al. 2020; Xu and Shi 2018). FA is commonly used as a partial cement replacement material, but this is mostly limited to replacement levels of 30% or less, with significant quantities of FA still not utilized globally. There have been no or little significant recent research into HVFAC to enable the utilization of FA and to reduce CO_2 emission by reducing cement demand (Herath et al. 2020). Therefore, an important investigation in this regard is the development of HVFAC that utilizes up to 60% of FA, and yet possesses excellent mechanical properties with enhanced durability performance. Consequently, in this study, an experimental effort was made to replace OPC by FA up to a replacement level of 60% (40%, 50%, and 60%).

Modern engineering technologies aim at producing ultra-high performance multifunctional concrete materials due to the increased demand for sustainability, durability and cost-effectiveness. Such construction materials are characterized by improved mechanical properties and long-term performance. They also integrate properties that encourage multiple applications making them sustainable for future uses (Makul 2020). Strength, workability and durability of concrete are the major aspects that are considered in the construction field. These properties are predominantly achieved through many of the recent advancements in the concrete technology. Mineral additives and chemical additives are the part of the modern concrete (Sathyan and Anand 2019).

The positive effects of FA as a partial replacement of cement on the strength and durability of concrete are recognized through numerous researches. But, another promising experiment needs to be conducted to investigate mechanical property such as compressive strength and workability, durability, cost effectiveness and environmental benefit of concrete adding FA (HVFA) and sugarcane molasses. Applications of concrete admixture are challenging in construction projects carried out in a country like Ethiopia because of the delicate nature of chemical admixture dosages and the lack of expertise that could control the ideal amount of the chemical admixtures to be added in concrete products. When the cost of acquiring chemical admixtures is taken into account, the difficulty increases since the cost of importing these chemical admixtures is high. In order to produce a comparable product at a lower cost and less complicated process than chemical additive, a method that sought to use concrete admixture made from local organic materials or industrial by-products must be developed.

In the last few decades, plasticizers and admixtures have become essential ingredients of concrete. Plasticizers facilitate the reduction of required water and the compactness of concrete, whereas, superplasticizers improve uniformity of concrete considerably. The distinguishing factor between these two is their origin: plasticizers are industrial by-products and superplasticizers are chemicals produced specifically for their intended use. Molasses is the waste product (by-product) of sugar industry and can be considered as a possible water-reducing admixture for concrete (Rashid et al. 2019). Molasses is used as a water reducing, retarding admixture in FA mixed concrete. Disposing of waste materials has adverse impact on environment. Therefore, waste materials like FA and molasses have been used as fractional replacement of cement and admixture respectively. Molasses as an admixture can be used for preparation of concrete. This means of utilizing molasses instead of conventional admixture will not only cut down the production cost of concrete but it will also enhance its resistance to compressive strength. It will also lead to the reduction in water utilization, expansion of setting time and likewise it can improve the durability, workability and quality of concrete mixture (Bhide et al. 2017).

To this end, the current study was conducted on the aim of investigating the mechanical properties (such as workability and compressive strength), water absorption and micro-structural properties of HVFAC in which molasses is used as an admixture. To realize this, physical properties of concrete ingredients and chemical characteristics of FA were experimentally investigated. The effect of HVFA and Molasses on fresh and hardened concrete was also determined. In addition, environmental and cost performance of using HVFA as partial replacement of OPC and Molasses as a plasticizer and retarder were also explored.

1.2 Statement of the Problem

The CI plays a pivotal role in shaping the modern world, but its environmental impact and resource consumption have raised significant concerns. Conventional concrete production, characterized by high cement content, contributes substantially to carbon emissions and energy consumption. To address these challenges, the exploration of alternative materials and additives is imperative (Habert et al. 2020). Although FA has been used as a partial substitute for cement, its utilization typically remains limited to replacement levels of 30% or less. This results in significant amounts of unused FA globally, while other industries continue to generate substantial waste materials like FA, which often end up in landfills, posing environmental challenges (Waqas et al. 2021). One such avenue involves the utilization of HVFAC as a sustainable alternative to conventional concrete, specifically in hot climates where DEF can jeopardize structural integrity.

However, the practicality and performance of HVFAC at higher replacement levels, such as 40%, 50%, and 60%, have not been thoroughly investigated. This gap in knowledge necessitates rigorous investigation to determine the physio-mechanical and micro-structural properties of HVFAC at these higher replacement levels.

While HVFAC presents a promising solution, there remains a need to optimize its properties, particularly its physio-mechanical attributes, to ensure its feasibility for mass concrete structures like bridges and dams. Additionally, incorporating novel admixtures into HVFAC formulations holds potential to further enhance its performance characteristics, both mechanically and environmentally. Organic additives such as sugarcane molasses which are readily available and processed with minimal complexity, offer more environmentally and economically conscious construction choices (Bhide et al. 2017). In this context, the integration of sugarcane molasses as an admixture stands out as an innovative approach, as it not only influences the concrete's mechanical properties but also offers the possibility of improved cost-efficiency and reduced environmental impact.

However, despite the growing interest in HVFAC and its potential benefits, a comprehensive investigation into the combination of high FA replacement percentages and sugarcane molasses admixture levels is lacking. The intricate interplay between these variables on the physio-mechanical and micro-structural properties of the resulting concrete has not been sufficiently explored. Moreover, the comparative assessment of these properties against traditional concrete is essential to ascertain the feasibility of implementing HVFAC with molasses admixture on a larger scale.

Therefore, the central problem driving this study is to comprehensively analyze the physio-mechanical and micro-structural characteristics of HVFAC incorporating sugarcane molasses as an admixture. Through this investigation, the study aims to shed light on the viability of this novel concrete formulation in terms of mechanical strength, workability, water absorption, and microstructure. Furthermore, the study seeks to evaluate the potential cost-effectiveness and environmental advantages of this alternative approach in contrast to conventional concrete, ultimately contributing to the development of sustainable construction practices.

In summary, this research endeavor addresses the gap in knowledge regarding the effects of high FA replacement percentages and sugarcane molasses admixture levels on the properties of HVFAC. By systematically investigating these aspects, the study strives to provide valuable insights that can inform the industry's transition towards more environmentally responsible and economically viable concrete production methods, particularly for mass concrete structures in hot climatic conditions.

1.3 Aim of the Study and Research Objectives

1.3.1 General Objective

The study aims to investigate the Physio-mechanical and Micro-structural properties of C-30 HVFAC incorporating sugarcane molasses as an admixture thereby to assess the cost and environmental performance of this new product as compared to the conventional one.

1.3.2 Specific Objectives

- To characterize the physical and chemical properties of the input materials of both HVFAC and conventional concrete.
- To study the Physio-mechanical and Micro-structural properties of concrete,
- To evaluate the cost and environmental performance of HVFAC incorporating molasses as compared to the conventional concrete.

1.4 Research Questions

Q1. Do the input materials of both concretes (HVFAC and conventional concrete) satisfy the physical and chemical requirements set by standard specifications?

Q2. Does the FA together with cane molasses affect workability of the concrete? And Does the FA together with cane molasses affect compressive strength, durability, and microstructure of the concrete?

Q3. Is a concrete made by utilizing HVFA as a partial replacement of cement and molasses as an admixture environmentally and cost wise efficient than conventional concrete?

1.5 Significance of the Study

Serious environmental concerns have been raised on the production of OPC in recent times and there has been significant increase in the generation of by-products and waste materials from industries, such as FA (Waqas et al. 2021). With the urgency of the issues under consideration, this research is aimed at magnifying the efforts made so far to replace the traditional OPC with environment friendly materials like FA with a significantly large quantity. The study aims also at making an earnest contributions towards decreasing the volume of the pollutants and CO_2 produced by cement production in addition to the improvement of mechanical properties of concrete. Furthermore, the study can contribute a bit to the increased demand for sustainability, durability and cost-effectiveness globally. Specifically, with the use of HVFAC incorporating sugarcane molasses, the practical contribution of the findings of the study primarily focuses on enabling stakeholders to overcome temptations regarding the construction of mass concrete structures such as dams, large bridges and building foundations where delayed ettringite (DEF) due to the high core temperature resulting from cement hydration and thermal cracking due to the high differential temperature between core and surface concrete are great concerns.

1.6 Scope of the Study

The experimental investigation covers only Index properties of the raw materials used and their characterization, the normal consistency test, the setting time test and the slump test for workability of fresh mix using slump cone test, compressive strength test at 7^{th}, 28^{th} and 56^{th} days curing period, water absorption for durability measurement and micro-structure (SEM and XRD) of hardened C-30 HVFAC incorporating cane molasses and conventional concrete too.

1.7 Organization of the Thesis

The current study's report is organized and presented into five basic chapters. General background, problem statement, objectives, research questions, significance, and scope of the study were included in the first introductory chapter. The second chapter provides a concise review of literatures that stated the study's matter. This section covers reviews of basic concepts of concrete and its ingredients; the meaning and the mechanical, durability and microstructural properties of HVFAC incorporating cane molasses. The relevant existing knowledge regarding the SCMs and industrial waste products as SCMs, physical and chemical characteristics of FA and cane molasses and the concept of modern concrete were also assessed in detail in this chapter with an inclusion of cost and environmental feasibility and research gaps. In Chapter 3, the research methodology is discussed in depth. After presenting the study's overall research methodology, the methodology adopted in individual objectives is discussed in this chapter. The fourth chapter presents all the findings of the experimental investigation and associated discussions in relation to sub-objectives in this chapter. Chapter 5 summarizes methodology followed and the findings of the various chapters and the study's conclusions. The chapter closes with this study's contributions to the literature, its limitations, and suggestions for further research.

1.9 Summary

In this chapter, after presenting the increasing demand of using concrete particularly environment friendly concrete in the CI to attain sustainable construction, the efforts needed to replace the traditional OPC with environment friendly material like FA with properties like OPC that will help to resolve the issues associated with the management of waste materials, improving concrete properties, reducing cost of concrete preparation, preserving the natural resources and simultaneously reducing the global warming effects, are discussed, and the problem statement and associated reasons that motivated this study are briefed. Afterward, the aim, research questions, and objectives set for this study and the research scope are outlined. Furthermore, the organization of the thesis to achieve these objectives is documented. The next chapter presents the literature on the overview of modern environment friendly concrete, the practices of using HVFAC with molasses used as an admixture, the mechanical and durability properties of HVFAC in which molasses added as a plasticizer and issues related with cost and environmental benefit of using such concrete.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

To develop a better understanding of the research objective, a comprehensive literature review has been conducted to identify the research gaps based on the objectives set. The general purpose of this chapter is to provide an extensive review of recent papers on PCC problems and their relevant solutions and the benefits of utilizing industrial by products like FA and cane molasses in a considerable amount. Hence, general concepts of concrete and its ingredients, concrete's mix design, concrete's casting and curing, fresh and hardened concrete tests, mechanical and durability properties of concrete, SCMs and the use of industrial waste products as SCMs, physical and chemical characteristics of FA and sugarcane molasses, the concept of modern concrete and the cost and environmental aspects of HVFAC incorporating sugarcane molasses were reviewed and presented in subsequent sections. And then the chapter closes by presenting the squeezed research gaps.

2.2 General Concepts of Concrete

Concrete has a dominant role in the modern construction engineering, as the second most-used material in the world after water it serves as a critical component for constructing the infrastructure necessary for the social and economic development (Kara et al. 2020). Concrete, a synthetic rock composed of cement, sand, gravel and water, is the fundamental building block of the urbanizing world, and by far the most widely used man-made material in the construction industry. Concrete is a critical component in the construction of our modern, industrialized society. For example, energy systems, water and wastewater systems, buildings — from single-floor houses to high-rise buildings — and transportation networks all rely on concrete (Habert et al. 2020). Hence, since this very essential artificial construction material is highly dependent on the quantity and quality of its components, proper attention has to be given to the selection of suitable ingredients as far as concrete production is concerned.

2.2.1 Concrete Ingredients

Since concrete is a composite material; it consists of different ingredients, such as binding materials, water and aggregates (Rashid et al. 2019). By definition, concrete mix is a mixture of cement, water, and coarse and fine aggregate, mostly enriched by additives and admixtures to improve some parameters, such as concrete strength, density, durability, or workability (Ziolkowski and Niedostatkiewicz 2019).

2.2.1.1 Cement

Cement is a binder material manufactured from limestone and clay and is a key ingredient in concrete (Rouch 2022). Cement is an essential component of concrete which is commonly used as building material worldwide (Zin et al. 2021). Cement is the mineral glue that binds sand and gravel together in concrete (Habert et al. 2020). Concrete is composed mainly of three materials, namely, cement, water and aggregate. An additional material, known as admixture, is only added at times to modify some of its properties. While cement remains the only chemically active constituent when mix with water, the aggregates seemingly play no part in the chemical reactions (Muritala et al. 2013). Cement is a hydraulic binder, i.e. a finely ground inorganic materials which, when mixed with water, forms a paste which sets and hardens by means of hydration reaction and processes and which after hardening, retains its strength and stability even under water (Gashaahun 2020). As a result, cement is the most vital ingredient for concrete preparation.

2.2.1.2 Fine and Coarse Aggregates

Concrete is composed of coarse aggregates and mortar, which itself is made of fine particles (e.g. sand grains) and cement. With a volume fraction of 40% to 50%, coarse aggregates play an important role in concrete mechanical properties (Wang et al. 2020). Normally coarse aggregate comprises 50–75% of the total volume of concrete (Ali and Ali 2019). The aggregate's usefulness arise because it is an economic filler with good resistance to volume changes which occur within the concrete after mixing, as well as improving the durability of the concrete. Aggregate is much cheaper than cement and maximum economy can be obtained by using as much aggregate as possible in the concrete while still retaining the required strength. It has also been noted by Muritala et al. (2013) that the commonly held view that aggregate is completely inert filler is not true. Its physical characteristics and in some cases its chemical composition affects to a varying degree the properties of concrete in both fresh and hardened states.

2.2.1.3 Water

Water is a crucial element in the concrete mix and is alone responsible for concrete work ability and cement hydration. In the realm of construction, concrete mixing requires potable water and curing and is highly helpful in the hydration process. Water is a crucial ingredient for hydration. Proper curing using impurity-free water is essential to reduce the hydration temperatures (Dharmaraj et al. 2021). The necessary amount of water for full hydration of cement varies from 20% to 25% of its mass, without taking into account the water trapped in the pores. According to Power's model, the water required to hydrate cement entirely is 42% by weight (Ziolkowski and Niedostatkiewicz 2019). In general, the quantity and quality of water have a major impact on the properties of fresh and hardened concrete.

2.2.1.4 Admixtures

According to the ASTM C494 (2001) standard, admixture is a material other than water, aggregates, and hydraulic cement that is used as an ingredient of concrete or mortar, and is added to the batch immediately before or during mixing. Admixture is substances introduced into concrete mixes to alter or improve properties of fresh and/or hardened concrete.

The admixture is generally added in a relatively small quantity ranging from 0.005% to 2% by weight of cement (Zongjin 2011). The widespread use of admixture is due to the many benefits made possible by their application. The usage of chemical admixtures in concrete is a common practice in modern construction, and the addition is to reduce water demand or improve concrete properties. Although the use of chemical admixtures provides better concrete properties, they are responsible for environmental pollution (Patel and Deo 2016). Besides the environmental pollution, some of the chemical admixtures are harmful to health during use in concrete especially those admixtures containing NO_2, other NOx, and CO_2 (Mahmood et al. 2021). Therefore, it is advantageous to identify substitute admixtures to create ecologically friendly concretes.

Researchers and scientists working on concrete all around the world are attempting to create non-chemical admixtures that are thought of as environmentally acceptable and eco-friendly building materials. Due to their abundance and their processing is not very sophisticated, organic or natural admixtures can be a practical choice for green construction. Admixtures and especially plasticizers have become indispensable components of concrete over the last decades (Akar and Canbaz 2016). Mahmood et al. (2021) also noted that molasses (a by-product of the sugar refining process) has been used as a natural admixture (NA) in concrete, and found to have water-reducing and retarding effects in concrete. Hence, referring to that, molasses can be used as a good substitute for a chemical admixture categorized as type-D (water reducing and retarding admixtures) as per ASTM C494 classification.

2.2.2 Concrete Mix Design

Concrete mix design can be defined as the process of selecting and determining the relative amounts of suitable constituents of concrete to produce concrete of required strength, workability and durability at minimum cost (Muritala et al. 2013). Concrete mix design is a complex and multistage process in which it can be attempted to find the best composition of ingredients to create good performing concrete (Ziolkowski and Niedostatkiewicz 2019). The main objective of concrete mix design is to determine the appropriate quantitative composition and quantity of concrete mixture components. A composition that enables to produce the best concrete performance should be used. Compressive strength and durability are the two most important characteristics of concrete performance among its other attributes. The design of the concrete mix should take both concrete strength and durability into account.

2.2.3 Concrete Casting and Curing

Concrete is expected to be placed right after the mixing of cement, aggregates, and water. Although it is desirable to place fresh concrete as soon as the mixing operation is completed, the placing of concrete in its final position might be delayed due to many reasons. Improper methods of handling of concrete, site organization, work scheduling, adverse environmental condition and breakdown of equipment are some of the causes for the unexpectedly long delay. Delay in casting can result in the cold joint and it can affect concrete strength as well (Mehedi et al. 2020).

Curing concrete is a crucial factor in achieving desired properties like strength and durability. It plays a major role, particularly in the initial stages of concrete, by facilitating cement hydration, regulating temperature, and controlling moisture movement in and out of the concrete. The primary objective of curing in the early stages is to prevent water loss from the concrete, so that it can gain strength during its initial days. For instance, Memon and Sam (2018) discussed related issue: Curing is also important to prevent plastic shrinkage, permeability loss and to improve resistance to abrasion. Concrete hydration starts when water contacts with cement causing chemical reactions and increasing the concrete's temperature. If the concrete is not cured and exposed to dry air it gets almost the 50% of the strength of cured concrete, if it is cured for 3 days it gets the 60-70%, but if it is cured for 7 days it gets 80-90% of fully cured concrete strength.

So the canon is that concrete should be covered for at least 7 days. The water loss of concrete occurs mostly from the surfaces exposed to the environment, where environmental humidity is lower than the humidity inside the concrete, which also results to reduced initial water-cement ratio and occurs due to cement hydration. According to Dinakar et al. (2013), curing has a significant influence on the pore structure of the concrete, the longer the curing time, more finely the pore structure and the capillary pores are less interconnected and moreover, the porous paste/aggregate interface zone formed at early ages is densified by continuous curing in water.

2.2.4 Concrete Properties

The required performance of concrete in both plastic and the hardened states is a factor in proportioning of concrete constituents. A plastic concrete that is not workable cannot be properly placed and compacted. The property of workability, therefore, becomes of vital factor. Also, the compressive strength of hardened concrete which is an index of its other properties, depends upon many factors such as quality and quantity of cement, water, aggregates, batching, mixing, placing, compaction and curing (Muritala et al. 2013). Concrete performance is characterized by several features, from which the most significant are compressive strength and durability (Ziolkowski and Niedostatkiewicz 2019). Strength, workability and durability of concrete are the major aspects that are considered in the construction field. These properties are predominantly achieved through many of the recent advancements in the concrete technology. Mineral additives and chemical additives are the part of the modern concrete (Sathyan and Anand 2019).

2.2.4.1 Workability of Concrete

According to ACI 116R, workability is that property of freshly mixed concrete or mortar that determines the ease and homogeneity with which it can be mixed, placed, compacted and finished to a homogenous condition. Concrete workability is defined as the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity. This property of concrete is generally known to affect the consistency, flow ability, pump ability, compatibility, and harshness of a concrete mix (Hoang and Pham 2016). Consequently, in order to make good quality concrete, concrete workability is a very important component that must be taken into account. Concrete of high quality has good workability, including deformability, water retention and segregation resistance.

The workability determines whether the concrete is suitable to cast in situ. In reality, if the workability of concrete was not qualified, the construction quality would be greatly influenced and even the strength could not fit the design standard leading to the safety of people (Yang et al. 2021b). The slump test is the most common method for assessing the flow properties of fresh concrete; the slump provides a measure of workability (Tuan et al. 2021).

In order to ensure that the concrete is appropriately positioned during construction and that the concrete achieves an adequate hardened strength after construction, it is required to monitor the workability of freshly mixed concrete. Both have an impact on the quality of the built environment, safety, and productivity. Fresh concrete with the right workability must be used if high-quality concrete structures are to be built safely and easily.

2.2.4.2 Strength of Concrete

Strength of concrete is a fundamental property of concrete, which reflects the maximum load concrete can handle without failure. The structure of hardened cement paste is directly related to the strength of concrete, offering a complete picture of concrete quality (P. Mehta and J. Monteiro 2014). Compressive strength of concrete is considered as the main engineering property of concrete and it has been considered as an index of quality control for many years (Kabir et al. 2013; Kovler and Roussel 2011). The compressive strength is one of the most effective parameters of hardened concrete. It gives a rough idea about the overall strength and durability characteristics of the concrete (Ali et al. 2020).

The compressive strength of concrete largely depends on the quality and quantity of cement as cement is the strength giver in concrete that binds the fine aggregate (usually sand) and coarse (gravel, crushed granites, etc.) together to form a rigid/solid mass that is capable of sustaining loads (Gupta 2019). Compressive strength is the primary aspect considered in many Studies (Herath et al. 2020). Compressive strength is a hardened concrete's capacity to withstand axial stress without deflection or fracture. It is essential for figuring out the mechanical characteristics of concrete samples. The most popular test for hardened concrete is the compressive strength test. Many codes and design manuals are based on this characteristic. Other properties of concrete are dependent on compressive strength, and it is easy to detect the concrete property when compared to other tests.

2.2.4.3 Durability of Concrete

Durability is the ability to resist weathering action, chemical attack, and abrasion while maintaining desired engineering properties (L.Wilson 2011). The water-tightness is greatly influenced by the amount of mixing-water, type and amount of supplementary cementing materials, curing, and cracking resistance of concrete. HVFAC mixtures, when properly cured, are able to provide excellent water-tightness and durability (Wang 2017). The important method to improve the durability characteristics of concrete is to reduce the permeability of concrete by giving good compaction (Sathyan and Anand 2019).

2.3 Basics of Cement

2.3.1 Types of Cement

There are over ten different types of cements that are used in construction purposes, and they differ by their composition and are manufactured for different uses. These are ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC), rapid- hardening cement (RHC), quick-setting cement (QSC), low- heat cement (LHC), sulphate-resisting cement (SRC), blast furnace slag cement (BFSC), high-alumina cement (HAC), white cement (WC), coloured cement (CC), pozzolanic cement (PzC), air-entraining cement (AEC), and hydro-phobic cement (HpC). RHC has increased the lime content compared to the Portland cement (PC). General use of the PC, Siliceous (ASTM C618 Class F) FA, Calcareous (ASTM C618 Class C) FA, slag cement, and silica fume in concrete is as primary binder, cement replacement, cement replacement, cement replacement, and property enhancer, respectively (Dunuweera and Rajapakse 2018).

OPC, also known as basic Portland cement, is a high-quality cement that may be utilized in extensive concrete production with little exposure to sulfates in the soil or groundwater, is the most commonly used building material worldwide and it will retain its status in the near future because of its demand and expansion of construction industry all over the world (Ikkurthi and Kanneganti 2017). According to their report but, for OPC to perform well in an aggressive environment, it should also be blended with some of the SCMs such as FA which have pozzolanic properties.

2.3.2 Chemical Composition and Hydration of Cement

2.3.2.1 Manufacture of Portland cement and Its Chemical Properties

Cement manufacturing uses energy to process raw materials consisting of mainly limestone (calcium carbonate, $CaCO_3$), clay (aluminum silicates), sand (silica oxide), and iron ore to produce clinker, which is ground with gypsum, limestone, etc. to produce cement (Gaharwar et al. 2016). The phase composition of Portland clinker varies according to the feed of the raw materials and methods used in its production. Clinker is a composition of Tricalcium silicate (Alite—C_3S), Dicalcium silicate (Belite—C_2S), Tricalcium aluminate (Celite—C_3A), and Tetracalcium aluminate (Brownmillerite—C_4AF) (Pizon et al. 2022). Different reports disclosed the approximate composition of the cement clinker. The summary of the phase chemical composition ranges of cement clinker is given in Table 2.1.

Table 2.1: Chemical Composition of Cement Clinker (Dunuweera and Rajapakse 2018; Ikkurthi and Kanneganti 2017; Pizon et al. 2022)

Compound	Formula	Notation	Mass %
Tricalcium silicate	$(CaO)_3.SiO_2$	C_3S	45-75
Dicalcium silicate	$(CaO)_2.SiO_2$	C_2S	7-32
Tri calcium aluminate	$(CaO)_3.Al_2O_3$	C_3A	0-13
Tetra calcium aluminoferrite	$(CaO)_4.Al_2O_3.Fe_2O_3$	C_4AF	0-18
Gypsum	$CaSO_4.2H_2O$	CSH_2	2-10

OPC is a controlled blend of calcium silicates, aluminates and ferrate which is ground to a fine powder with gypsum and other materials. After 1987, OPC was divided in three types based on the strength obtained by 28 days (Ikkurthi and Kanneganti 2017). The types are as follows:

- OPC 33 grade – strength not less than 33N/mm2 at 28 days
- OPC 43 grade – strength not less than 43N/mm2 at 28 days
- OPC 53 grade – strength not less than 53N/mm2 at 28 days

Lime, silica, alumina, and iron oxide are the main source of raw materials for PC production. These oxides carry out complex reactions in the kiln at high temperatures to form complex compounds. The chemical components of PC are reported in terms of oxides. The Chemical properties of cement are determined from the chemical analysis of these raw materials (Ikkurthi and Kanneganti 2017). As demonstrated in Table 2.2, CaO accounted for 61 to

67% of cement oxide, while SiO_2 accounted for 19 to 23%. When compared to lime, alumina and ferric oxide contribute very little.

Table 2.2: Chemical Composition of OPC (Ikkurthi and Kanneganti 2017; Rouch 2022)

Oxide	Common Names	Formula	Mass%
Calcium oxide	Lime	CaO	61-67
Silicon dioxide	Silica	SiO_2	19-23
Aluminum oxide	Alumina	Al_2O_3	2.5-6
Iron Oxide	Ferric Oxide	Fe_2O_3	0-6
Sulphur Trioxide	Sulphate	SO_3	1.5-4.5

The foremost compounds in PC are C_3S, C_2S, C_3A, and C_4AF. Among which C_3S and C_2S are the essential compounds that contribute to the strength of cement paste. The inclusion of C_3A in cement aids early strength. C_4AF is also found in small concentrations in cement, and it has little effect on behavior when compared to the other three compounds. High C_3S (low C_2S) percentages produce a lot of early strength, but they also produce a lot of heat while the concrete cures. Low C_3S and high C_2S, on the other hand, develop strength more slowly and produce less heat. C_3A creates undesirable heat and has a rapid reaction rate, (Dunuweera and Rajapakse 2018). According to this study, it has also been reported that the addition of pozzolanic admixtures such as FA reduces the C_3A content of cement.

2.3.2.2 Normal Consistency of Cement

A normal consistency of cement paste is defined as a percentage of water by weight of cement that allows a standard plunger of 10 mm diameter to penetrate up to a depth of 5 to 7 mm above the bottom of Vicat's mold. The Higher values of normal consistency of cement paste are observed when cement is old and when the cement is too fine that has a high specific surface area (Dinku, 2002). According to ASTM C187 (2016), normal consistency is expressed as a percentage of dry cement weight and ranges from 22 to 30.

2.3.2.3 Cement Hydration

PC hydration is a sequence of overlapping chemical reactions between clinker components, $CaSO_4 \cdot 2H_2O$ and water, leading to the cement setting and eventually hardening (Li et al. 2015). PC obtains its strength as a result of chemical reactions between cement and water. The process is known as hydration. This is a complex process that is best understood by elucidating the chemical composition of cement (Ikkurthi and Kanneganti 2017). The concrete hardening is started by the cement hydration process, which is an exothermic chemical reaction between cement and water. Hydrated cement forms a tobermorite gel, hydroxide, and some secondary compounds that help with bonding between the fine and coarse aggregate. In the course of the hydration process, the hydration products gradually deposit on the original cement grains and fill the space occupied by water. The hydration process stops when there is no unreacted cement or the water molecules are retracted (Ziolkowski and Niedostatkiewicz 2019).

Both C_3S and C_2S react with water to form an amorphous calcium silicate hydrate known as C–S–H gel, which serves as the primary 'glue' that holds sand and coarse aggregate particles together in concrete. When water and PC are combined, the constituent compounds of the cement and water undergo a chemical reaction that causes the concrete to harden. Each substance found in cement reacts with water at a different rate. The most reactive compounds are C_3S and C_3A, whereas C_2S reacts more slowly (Pizon et al. 2022). Approximately half of the C_3S present in typical cement will be hydrated by three days and 80% by 28 days. In contrast, the hydration of C_2S does not generally begin until about 14 days. The C_3S is hydrated to produce C-S-H, lime, and heat, while the C_2S also hydrates to form C-S-H and heat (Rouch 2022). As per Rouch (2022), Equation 2.1 to Equation 2.7 illustrate the hydration mechanisms of cement:

The reaction of tri-calcium aluminate C_3A [Equation 2.1]

The first phenomenon occurs almost instantly when water is added. Specifically, some of the clinker sulfates and gypsum dissolve to form a sulfate alkaline solution. Afterwards, a series of reactions occur, starting with the most reactive mineral, C_3A. During the hydration of cement, C_3A first reacts with water to form an aluminate-rich gel. This gel then reacts with sulfates to form ettringite crystals. The reaction of C_3A generates high heat of hydration, but only for a short period of time. Then the heat relatively decreases for several hours in the induction period.

$$C_3A + 3CSH_2 + 26H = C_6AS_3H_{32} \text{................................ Equation 2.1}$$

The reaction of tri-calcium aluminate C_3S [Equation 2.2]

Following the induction period of the reaction in Eq.2.1, C_3S starts reacting to produce C-S-H gel and calcium hydroxide (CH).

$$2C_3S + 6H = C_3S_2H_3 + 3CH \text{................................ Equation 2.2}$$

The reaction of unstable ettringite [Equation 2.3]

Once gypsum is depleted due to the first reaction, the ettringite becomes unstable. In fact, it starts reacting with the remaining C_3A during the hydration of cement. This reaction produces mono-sulfate aluminate hydrate crystals (C_4ASH_{18}).

$$2C_3A + 3C_6AS_3H_{32} + 22H = 3C_4ASH_{18} \text{................................ Equation 2.3}$$

The reaction of di-calcium silicate C_2S [Equation 2.4]

Similar to the reaction of C_3S, C_2S reacts with water to form C-S-H gel and CH.

$$C_2S + 4H = C_3S_2H_3 + CH \text{................................ Equation 2.4}$$

The reactions of tetra-calcium aluminoferrite C_4AF with Gypsum [Equation 2.5]

In addition, C_4AF undertakes two subsequent reactions with gypsum during the hydration of cement. First, ferrite reacts with gypsum to form alumina or ferric hydroxides, ettringite, and lime.

$$C_4AF + 3CSH_2 + 3H = C_6(A \text{ or } F)S_3H_{32} + (A \text{ or } F)H_3 + CH \text{............. Equation 2.5}$$

Afterwards, ferrite also reacts with the ettringite and lime produced previously, in the presence of water, to produce complex compounds. However, these compounds only fill voids and do not contribute to strength development of concrete.

The reactions of tetra-calcium aluminoferrite C_4AF with Ettringite [Equation 2.6]

$$C_4AF + C_6(A \text{ or } F)S_3H_{32} + 2CH + 23H = 3C_4(A \text{ or } F)SH_{18} + (A \text{ or } F)H_3 \text{..........Equation 2.6}$$

The pozzolanic reaction [Equation 2.7]

Furthermore, CH produced by the reaction of C_2S and C_3S reacts with amorphous silica to produce additional C-S-H gel. This reaction occurs in the presence of pozzolanic materials (natural SCMs and artificial SCMs), which are rich in amorphous silica, thus known as the pozzolanic reaction.

$$Ca(OH)_2 + H_4SiO_4 = CaH_2SiO_{42}H_2O \text{................................ Equation 2.7}$$

The FA pozzolanic properties render it beneficial for the replacement of cement in concrete. FA increases workability, decreases the hydration heat, and thermal cracking in cementitious materials at initial ages, and improves the mechanical and durability characteristics of cementitious composites, mostly at later ages. The amorphous silica in FA reacts with the CH released by CaO hydration producing Ca_2SiO_4 hydrate to form C-S-H (Mohamed and

Khallaf 2022). As a result of this reaction, additional strength can be gained at late ages, superior strength concrete in which cement is replaced by FA partially. Due to the pozzolanic process, the strength gain lasts significantly longer than with normal concrete.

2.3.2.4 Setting Time of Cement

The cement paste setting time is the length of time it takes for the cement paste to lose its plasticity after it has been combined with water. Cement setting time is classified into two types: initial and final setting time. The time elapsed between adding water to the cement and the paste losing its flexibility and hardening is referred to as the initial setting time. While, final setting time is the time interval between when water is added to the cement and when the paste has completely lost its plasticity (Kassa 2019). According to ASTM C150 (2018), the initial setting time should not be less than 45 minutes, and the final setting time should not be more than 375 minutes. According to Ethiopian standards, the initial setting time for cement should not be less than 45 minutes, and the final setting time should not be more than 600 minutes (Dinku, 2002).

2.3.3 Environmental Impact of Cement Production

Cement is produced by utilizing an extensive amount of raw materials treated and reacted at extreme conditions such as high temperatures. The high-temperature processes are called pyroprocessing processes where raw materials are heated at high temperatures for solid-state reactions to take place, which utilize fuel sources such as coal, fuel oil, natural gas, tires, hazardous wastes, petroleum coke, and basically anything combustible (Dunuweera and Rajapakse 2018). Cement, is currently produced at a rate of around 4 gigatonnes (Gt) per year, a rate comparable to global food production. Over the last 65 years, cement consumption has increased tenfold, a huge change considering steel production has only increased by a factor of three and timber construction has stayed nearly constant in the same time frame (Habert et al. 2020). Cement manufacturing is an environmentally unfriendly procedure because of the release of CO_2 gases into the atmosphere and natural useful resource degradations. PC clinker production is one of the major sources of CO_2 and other GHGs within the contribution of 5 % of the annual global atmospheric CO_2 emission (Gashaahun 2020).

The global cement industry contributes around 2.8 billion tons of the GHG emissions annually, or about 7-8% of the total man-made GHG emissions to the earth's atmosphere (Herath et al. 2020; Vora and Dave 2013; Zin et al. 2021). Portland clinker is an energy-extensive procedure, in which raw substances are burned at 1450°C and the cement sector is the arena's third-biggest industrial power consumer, accounting for 8% of industrial energy intake (Rouch 2022). According to a study, 1.6 tons of raw materials are consumed for the production of one ton of cement that will result in the liberation of 1 ton of CO_2 in the atmosphere (Waqas et al. 2021). The cement industry faces demanding situations that include rising energy charges, insufficient necessities to reduce CO_2 emissions, and raw materials delivery.

A leading trend to mitigate the negative environmental impact of cement production is the use of waste materials (Pizon et al. 2022). Replacing parts of the cement in concrete with SCMs, or making blended cement where clinker is partly replaced with SCMs, is the fastest short term remedy to reduce CO_2 emissions from the cement and concrete industry (Justnes 2015). To lessen the environmental impact of cement manufacturing, many research recommend using supplemental cementitious materials as a partial cement replacement.

2.4 Supplementary Cementitious Materials

A new area of civil engineering is the use of additional or substitute materials for cement. Due to the challenge of material scarcity and the necessity to combat global warming, concrete's constituents have evolved. Herath et al. (2021) reported that in the attempt to develop sustainable building materials, several supplementary cementitious materials (SCMs) have been used as alternatives to replace cement in concrete and thereby reduce CO_2 emission by minimizing cement production . In addition, inclusion of SCMs utilize the available waste material generated as industrial by-products, thereby mitigating the issues associated with the dumping and disposal of such materials (Herath et al. 2021). Large amounts of SCMs are currently being used in concrete as the SCMs can reduce costs, reduce carbon emissions, improve sustainability, and make the concrete more durable (Suraneni and Weiss 2017).These authors further elaborated in their report that SCMs modify cement hydration in complex ways. SCMs have a filler effect due to their physical presence (an increase in cement hydration extent due to nucleation on the SCM surface, dilution of cement leading to higher space availability for hydrate formation, dilution of cement resulting in a change in the pore solution, and reduction in interparticle distance leading to a higher number of nucleation sites.

Due to continuous increasing demand and the cost of cement, recently, the utilization of SCMs such as industrial by-product (fly ash, silica fume and slag) and agricultural wastes (rice husk ash, palm oil fuel ash, bagasse ash and ash from timber) has become an important issue for the researchers in concrete industry. Fly ash (FA), one of these valuable industrial wastes, is generated as by-product from power generating industry. The production of FA increases every year, it is disposed for landfills without any commercial gain and now becomes a trouble (Karim et al. 2011).

2.4.1 Pozzolana

The Phoenicians, Greeks, and Romans noticed that when certain natural materials were mixed with lime, they produced mortars and concrete that could harden under water. These products are known as natural pozzolans, named after the city of Puzzoli near Naples where the Romans extracted some particularly reactive volcanic ashes from Vesuvius (Aïtcin 2016). 'Pozzolanic materials are natural substance of siliceous or silico-aluminous composition or a combination thereof". Pozzolanic materials react at normal ambient temperature with dissolved calcium hydroxide ($Ca(OH)_2$) to form strength-developing calcium silicate and calcium aluminate compounds. Currently, a large quantity of pozzolanic materials (such as fly ash, slag powder and others) have been produced in industrial production process, which can be used as SCMs in cement concrete (Zhang et al. 2020). The characterization of pozzolanic historic mortars revealed that two types of pozzolans have been used in the past: natural, usually of volcanic origin and artificial like ceramic powder (Moropoulou et al. 2004).

2.4.1.1 Natural Pozzolana

Natural pozzolans are usually materials of volcanic impact or origin, or sedimentary rocks with suitable chemical and mineralogical composition. They are made up by nature of amorphous or poorly crystalline siliceous compounds available in certain regions only and react in the presence of water at ambient temperatures with dissolved $Ca(OH)_2$ to form C-A-S-H phases. Their pozzolanic reactivity varies and is determined by the content of reactive silicon dioxide and alumina (Schneider 2019). Presently, the use of pozzolanic materials and what are called SCMs is becoming very important, because the sustainability of concrete structures is becoming a fundamental criterion.

2.4.1.2 Artificial Pozzolana

The group of artificial SCMs/Pozzolans includes materials which have undergone structural modifications as a consequence of manufacturing or production processes. Artificial SCMs can be produced deliberately, for instance by thermal activation of kaolin-clays to obtain metakaolin, or can be obtained as waste or by-products from high- temperature processes such as blast furnace slags, fly ashes or silica fume (Snellings et al. 2012). It is also noted by Zhang et al. (2020) that artificial pozzolans shall now not increase the water demand of the cement appreciably, impair the resistance of the concrete or mortar to deterioration in any manner or reduce the corrosion protection there in reinforcement.

2.4.2 Industrial Waste Products as Supplementary Cementitious Materials

Fly ash (FA), blast furnace slag and silica fume are some of the most commonly studied industrial waste materials as cement alternatives. Among these SCMs, a major focus has been on the utilization of FA due to its abundant availability, compatibility and low cost (Herath et al. 2021). FA, silica fume, bagasse ash, and slag are the supplemental cementitious materials that are employed most frequently because of their finer particle size and pozzolanic action when combined with cement and water. In recent years, the use of industrial byproducts as a substitute for nonrenewable materials in the production of cement and concrete has drawn substantial attention for sustainable development goals.

Inappropriate handling of solid industrial waste can lead to leachate penetrating soil and groundwater, causing environmental irreversibility and endangering human health; moreover, global warming and climate change are the two most serious environmental problems caused by CO_2 emissions. The CI substantially impacts the environment, accounting for a significant portion of CO_2 emissions. Each ton of cement produced emits about 0.8 tons of CO_2, and cement production is increasing globally due to the increasing demand for concrete. Researchers worldwide are constantly on the lookout for new materials that can be utilized in place of, or in addition to, cement. Since the last decade, the application of SCMs such as silica fume, FA, slags, etc., as a cement replacement has been emphasized. SCMs hydrate cement hydraulically or pozzolanically in pore solution (Mohamed and Khallaf 2022). Using industrial solid waste as SCMs in construction is a viable way to promote eco-friendly building practices. This approach can potentially decrease the need for cement, lower CO_2 emissions, and offer a solution for waste disposal concerns.

Among the different types of industrial byproducts that can serve as SCMs, FA is the most frequently utilized. Materials such as FA, blast furnace slag, silica fume, and metakaolin can serve as partial substitutes for PC in concrete. These additives have several benefits, including improved durability, reduced risk of thermal cracking in large concrete structures, and lower embodied energy and carbon footprint compared to PC. Mostly siliceous FA, which show pozzolanic properties, are used as cement constituents leading to better workability and positive long-term strength of concrete as well as good durability characteristics due to a denser concrete structure (Schneider 2019).

2.4.3 Fly Ash

Fly ash is a waste residue that is released from coal combustion process in electric power stations. There are two classes of FAs for their use in concrete, class F and class C. Class F is a pozzolanic FA normally produced from burning anthracite and bituminous coals and will have minimum SiO_2 +Al_2O_3 +Fe_2O_3 of 70 wt.%. Class C is a pozzolanic and cementitious FA derived from burning lignite or subbituminous coal and will have minimum SiO_2 +Al_2O_3 +Fe_2O_3 of 50 wt.% (ASTM C618 2019). FA is a heterogeneous powder, which is the main residue of coal combustion. FA particles tend to be spherical in shape, micrometers to millimeters in dimensions, and they can be highly reactive, depending on the chemistry of the individual particle. Such reactivity has caused its demand to grow steadily over past 30 years, especially as a low-cost binder in the concrete and construction industries (Aboustait et al. 2016).

2.4.3.1 Physical and Chemical Characteristics of Fly Ash

There is wide variation in the chemical and physical properties of FA depending on the coal source, the type of coal burnt, the boiler used and its operating conditions and the process undergone by coal before combustion. Collection and storage conditions may also affect the characteristics of ash (Panda and Dash 2019). Therefore, a thorough understanding of FA's physical properties, chemical makeup, and mineralogy is necessary in order to comprehend its likely environmental effects and take into account its prospective applications.

The properties of FA mainly depend on types of coal and its pulverization, burning rate, temperature, method of collection etc. The concentration of unburned carbon (UC) and iron present in the FA determines the color of the material. It is generally observed that grey or black color ash obtained when the amount of carbon content is higher while presence of high iron content produces tin colored ash. Most of the FA particles are solid spheres and some are hollow spheres. The particle size ranges from 0.5µm to 100µm. This micron sized particle consists mostly of silica, alumina, calcium and iron oxide. Besides, minor amounts of magnesium, Sulphur, sodium, potassium, and carbon are also present in it (Gorai 2018; Kim et al. 2020). FA is a powdery solid that is constituted mostly of UC, metal oxides (Si, Fe, Ca, and Al), and other inorganic substances. UC is an inexpensive source of activated carbon that plays an important role in FA adsorption capacity. Due to the broad variability in its composition, FA characterization is challenging. Accordingly, FA is categorized into class F, and class C according to the maximum and minimum % of SiO_2, Al_2O_3, Fe_2O_3, and SO_3 (Alterary and Marei 2021). As a result, deeper comprehension of the material's physical and chemical properties is crucial due to the rising demand for FA and the distinctive features that must be present for each application.

Furthermore, the specific surface area (SSA) of FA has a significant effect on its pozzolanic reactivity and on the performance of FA-blended concrete. Because FA contains a considerable amount of irregularly shaped particles and UC, determination of an accurate SSA is analytically troublesome by conventional methods (Wang et al. 2018). It was also reported that the average size of FA fine particles is less than 20 microns, with a bulk density of 0.54–0.86 g/cm3, a surface area of 300–500 m2/kg, and a pH value of 1.2–12.5, with most ashes tending toward alkalinity (Ge et al. 2018). The analysis of the application and disposal of FA, particularly its use as a cement substitute material, heavily relies on the chemical and mineralogical composition of FA. In Table 2.3, the summary of the different physical properties of FA is shown (Panda and Dash 2019).

Table 2.3: Summary of the different physical properties of fly ash

Number	Parameter	Range	Methodology
1	Bulk density: g/cm^3	1.97- 2.89	Bulk method
2	Particle size: mm	0.01-	Sieve and hydrometer analysis
3	Specific gravity	1.6- 3.0	Pycnometer method
4	Specific Surface area: m^2/kg	170- 1000	BET nitrogen (N_2) method
5	Porosity: %	30- 65	Mercury intrusion porosimetry
6	Water-holding capacity: %	40- 60	Column-centrifugation method
7	Dielectric constant	10^4	Impedance analysis
8	Permeability: cm/s	10^{-4}- 10^{-6}	Falling-head permeability test
9	Optimum moisture content:	18- 38	AASHTO T99 TEST

Regarding micro-structural properties, FA particles have a spherical make and a glossy surface. The spherical particles may either be compact or contain voids in them (Ge et al. 2018). Microstructural examination of FA samples following early curing reveals an abundance of un-hydrated spherical FA particles. Despite this, after a year of curing, the microstructure of FA samples appeared to be very compact, with no evidence of dehydrated FA particles (Mohamed and Khallaf 2022). Figure 2.1 shows scanning electron microscope (SEM) images of the raw typical FA morphology taken from a review done on characterization and utilization of coal FA and which has been reported by P.Laxmidha and D.Subhakanta (2019).

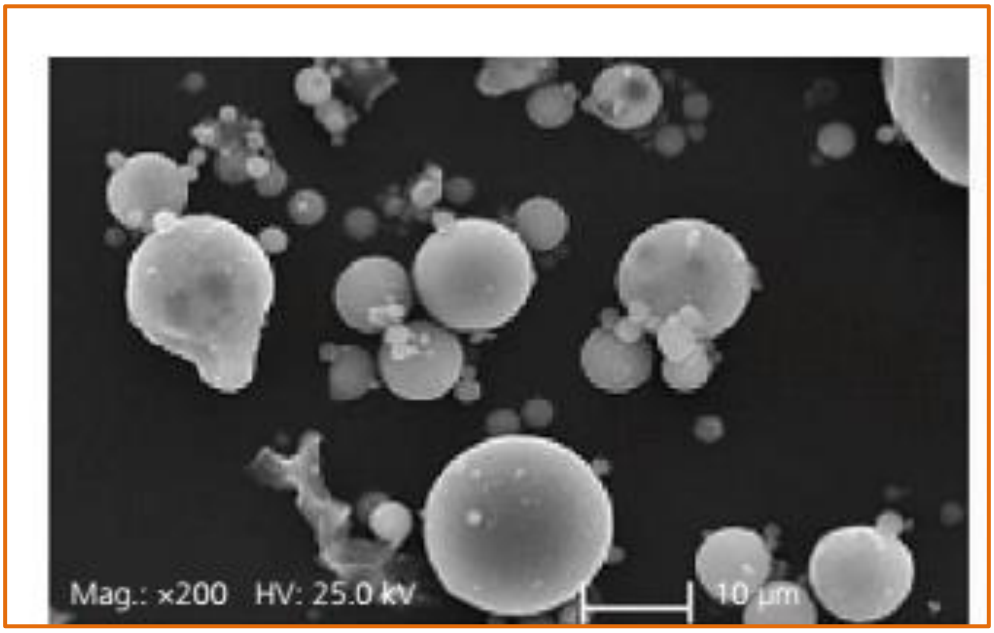

Figure 2.1: Typical SEM images of fly ash

Beside this, X-Ray Diffraction (XRD) analysis has been used to establish the presence of minerals in FA. XRD study reveals that FA possesses both crystalline and amorphous phases. The dominant crystalline phases are quartz, mullite, kaolinite, lime and siderite with trace amounts of magnetite and hematite (Kim et al. 2020; Tydlitát et al. 2018). The amorphous glass phase is responsible for its properties (Gołaszewski et al. 2020). As reported by Kim et al. (2019), quartz and mullite are the major crystalline phases in low-calcium FA, whereas quartz (SiO_2), tri-calcium aluminate ($Ca_3A_{l2}O_6$) and calcium silicate (Ca_2SiO_4) are the major phases in high-calcium FA. Mullite is not supposed to be an ingredient of coal but is formed during the thermal decomposition of the mineral kaolinite. Figure 2.2 shows the XRD image of a typical FA ((Panda and Dash 2019).

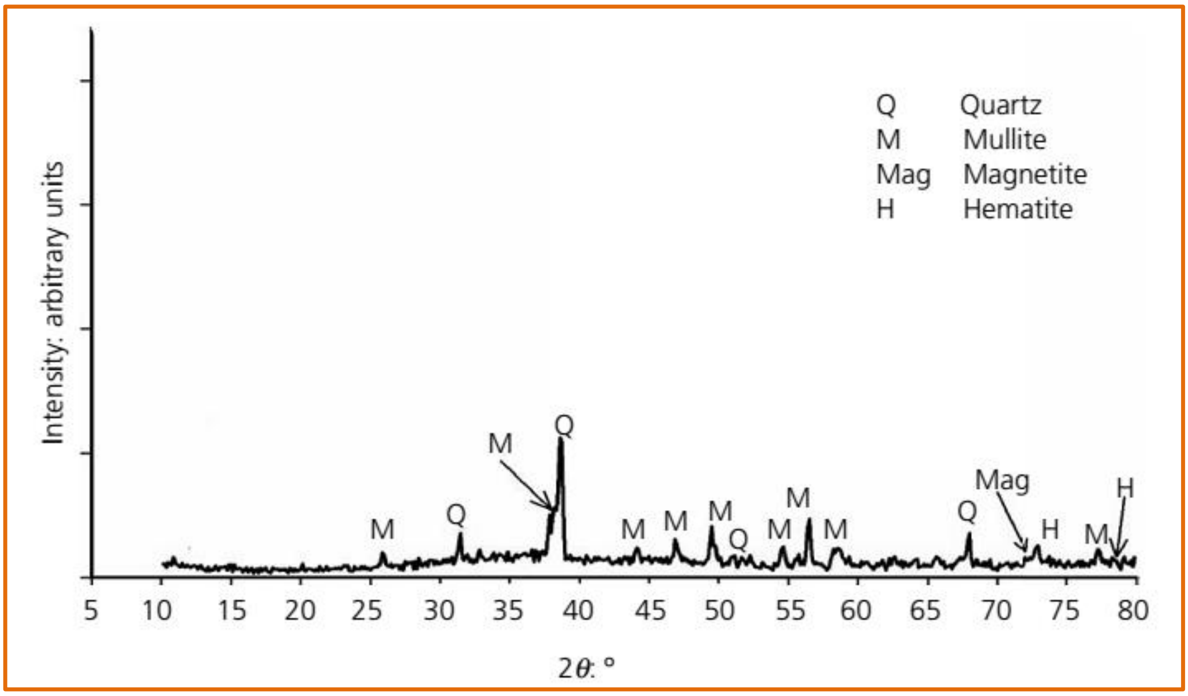

Figure 2. 2Typical XRD pattern of raw fly ash

2.5 Molasses

Molasses is a viscous by-product of the refining of sugarcane, grapes, or sugar beets into sugar (Weifeng et al. 2014). Molasses, a by-product of sugar industry, is used as a water reducing, retarding admixture in FA mixed concrete (Bhide et al. 2017). Sugar and sugar acids can adsorb both CSH and $Ca(OH)_2$ nucleation sites and poison them. Hence, molasses has the potential of being used as concrete water reducing and retarding admixture.

Molasses, as a by-product of the sugar plant, has been proven as a type D admixture for Portland cement (Huang et al. 2020). In addition to efficiently delaying PC's hydration, molasses also makes the material more workable. Molasses is generally used as a grinding aid in cement and as a water reducer and retarder in concrete.

In Ethiopia there are thirteen sugar factories and molasses has been produced in Ethiopia since 1954/55 when the first sugar factory was established in Wonji (Serte 2019). In the year 2018, the sugar production amount was 51 million tons; however, in 2023 this amount will be increased to 74 million tons (Ethiopian Sugar Corporation Communication department, 2020). Since the retarding and water reducing chemical admixtures are expensive to import by foreign currency, sugarcane molasses, a locally sourced admixture, can be a good substitute.

2.5.1 Physical and Chemical Characteristics of Molasses

Sugarcane molasses, a by-product from sugarcane refining, is a thick and dark syrup, resulting from the crystallization and removal of the majority of sucrose from the original juice (Xu et al. 2015). Xu et al. (2015) conducted an experiment to determine sugars in molasses by High Performance Liquid Chromatography (HPLC) following solid-phase extraction and the results showed that the linear ranges for fructose, glucose, and sucrose were 3.30–16.48, 1.80–9.02, and 5.94–29.70 g/L respectively. According to this study in general, molasses contains about 50% sugar by dry weight, predominantly sucrose, fructose, and glucose. Furthermore, unlike refined sugars, molasses contains trace amounts of vitamins and several minerals.

16 cane and 16 beet molasses samples were sourced worldwide and analyzed for chemical composition by Palmonari et al. (2020). The summarized results of the chemical composition of the cane molasses is provided in Table 2.4.

Table 2.4: Descriptive statistics of the chemical composition (% of Dry Matter, DM) of cane molasses (Palmonari et al. 2020)

Item	Dry matter	Total sugar	Sucrose	Glucose	Fructose	Raffinose	Galactose
Min.	75.7	57.0	39.2	1.30	2.30	0.02	0.04
Max.	79.6	71.0	67.3	12.07	14.28	0.03	0.04
Aver.	76.8	62.3	48.8	5.29	8.07	0.03	0.04

Item	Lactic acid	Citric acid	Acetic acid	Ash	Ca	Mg	Na	K
Min.	1.62	0.08	0.16	10.2	0.82	0.19	0.01	0.31
Max.	12.75	0.22	1.04	16.3	3.13	0.63	0.42	7.99
Aver.	6.10	0.13	0.44	13.1	1.39	0.43	0.08	1.82

Molasses are specifically preferred by cement factories for their economical and logistics benefits. Additionally, composition of molasses does not contain any toxic materials; therefore, using molasses in cement production is less harmful to environment (Li et al. 2015).

2.5.2 Effect of Molasses on Workability of Concrete

Sugarcane molasses can be used as a cheap substitute of the conventional plasticizer to reduce the water demand (Ali and Ali 2019). Sugar can be used as a surface-active agent to improve the workability of concrete. For sugar dosages of 0.03 and 0.06 %, the required amount of water decreased by 4 and 5 %, respectively (Weifeng et al. 2014). Plasticizer can be added to the cement-based materials for improving the workability; retarder can be added to retard the hydration reaction and prevent the quick loss of workability (Huang et al. 2020). Molasses addition can improve the properties of normal concrete by reducing the water demand (Ali and Ali 2019).

In another study conducted by Huang et al. (2020), evaluation of molasses as a retarder and plasticizer for calcium sulfoaluminate (CSA) cement-based mortar was undertaken and the influence of molasses dosages on the workability was examined. Consequently, it was found that CSA cement paste without molasses addition was very stiff, with a flow diameter of 116 mm. The flow diameter of CSA cement paste increased noticeably with the increase of molasses dosage; it reached 220 mm at a molasses dosage of 1%. Molasses showed similar performances with some superplasticizers. For instance, Li et al. (2018) found that naphthalene-based superplasticizer improved the flow diameter of CSA cement paste to 220 mm at a dosage of 0.9%. Molasses was begun to use as mid-range plasticizer thanks to its water reducing properties (Akar and Canbaz 2016).

2.5.3 Effect of Molasses on Setting Time of Cement Paste

Molasses not only improves concrete fluidity but also prevents early hardening of cement paste (Rashid et al. 2019). The researchers further elaborated in their report that it was recognized that the adsorption of sugar and sugar acids on the surfaces of hydrating cement particles along with hydration products lead to retarding action. Addition of sugar in concrete in small amounts delays the hydration reaction of cement (Yildirim and Altun 2012). An experiment was done by S. Pathan (2017) to determine setting times of concrete prepared with molasses at three different dosage (0.40, 0.60, and 0.80 wt. % of cement content) and it was found that molasses addition causes considerable increase in both initial and final setting time. Retarders such as molasses are used to reduce the setting time by reducing the rate of cement hydration and therefore are preferred in high temperature concreting places (Mahmood et al. 2020).

2.5.4 Effect of Molasses on Compressive Strength of Concrete

Molasses as an admixture can be used for preparation of concrete. This means of utilizing molasses instead of conventional admixture will not only cut down the production cost of concrete but it will also enhance its resistance to compressive strength (Bhide et al. 2017).

The concretes made with sugar addition show strength reduction at early ages, but their later age strengths might be higher (Yildirim and Altun 2012).

An experimental test to investigate the effect of sugarcane molasses, with concentrations of 0.1%, 0.15%, 0.2% and 0.25% by weight of cement, on Compressive strength and workability of FA mixed concrete cured at 7, 28 and 56 days has been conducted by Bhide et al. (2017). The compressive strength test results showed significant strength gain at all ages for 0.15% dosage molasses but peaks at 43.89% at 28 days. However, there was no significant increase in strength from 28 to 56 days which peaks 4.8% for 0.15% dosage.

The compressive strength of concrete was also examined in a research done by Kassa (2019) to evaluate the application of cane molasses with varying dosage (0%, 0.025%, 0.075%, 0.10%, 0.15%, 0.2%, and 0.30% by weight of cement) as concrete retarder admixture. His study findings depicted that, at the 0.1% molasses dosage, the highest strength development throughout all its age was observed; 25.4 MPa, 30.12 MPa, and 33.92 MPa were recorded for 7, 14, and 28 days, respectively. This shows molasses has been utilized as an admixture in concrete production to enhance mechanical properties of concrete though the optimum dosage and the corresponding strength gain varies.

2.5.5 Effect of Molasses on Durability of Concrete

Water absorption (WA) is the indirect measure of permeable porosity of concrete. Higher porosity leads to a faster introduction of foreign chemicals (gases or liquids) that can destroy the chemical stability of particles in the microstructure of concrete. Therefore, absorption can be taken as the rough measure of the durability of concrete (Ali et al. 2020). WA is a relative measure of durability because it is an indirect measurement of accessible porosity of concrete (Kumar et al. 2016). A study was conducted by Ali and Ali (2019) to examine the durability of recycled aggregate concrete (RAC) modified with sugarcane molasses. The influence of various dosages of molasses (0%, 0.01%, 0.05%, 0.1%, 0.5%, and 1% by weight of cement) was investigated on the properties of both RAC and natural aggregate concrete (NAC). Maximum reduction in water absorption of RAC was observed at 0.1–0.5% molasses. This can be ascribed to improvement in the density of both RAC and NAC at these dosages.

Utilizing molasses instead of conventional admixture will not only cut down the production cost of concrete but it will also enhance its resistance to compressive strength. It will also lead to the reduction in water utilization, expansion of setting time and likewise they improve the durability, workability and quality of concrete mixture (Bhide et al. 2017). Therefore, using molasses in place of admixtures at a wide scale in concrete will be extremely beneficial in terms of strength, durability, cost, economy, energy efficiency, and overall ecological and environmental benefits. The summary of reviewed works of different researchers in which molasses has been utilized as an admixture is presented in Table 2.5.

Table 2.5: Summary of reviewed works (associated with molasses usage) of different authors

Study Title	Molasses Dosage (in % by weight of cement)	Main Findings	References
Effect of molasses as an admixture on concrete durability	0.5%, 1%	Increased Slump amounts	(Akar and Canbaz 2016)
		Significant extension in setting time (up to 24hr) with the 0.5%	
		Improvement of by compressive strength 20% @ 28th day with the 0.5% dosage	
		Reduction in concrete cost by 3%	
Study The Effect of Coal Bottom Ash on Partial Replacement of Fine Aggregate in Concrete With Sugarcane Molasses as an Admixture	0.01%	Compressive strength improved by 7.5% @ 28th day	(Kumar et al. 2016)
		Reduced WA up to 30% coal bottom ash and 0.01 molasses combination	
Using Molasses in Concrete As A Time Retarding Admixture	0.4%, 0.6%, & 0.8%	Workability increased as the dosage of molasses increased	(Pathan 2017)
		Considerable increase in both initial and final setting time	
		A slight increase in compressive strength @14th & 28th day but decreased @ early age (7th day)	
		Low cost and environment-friendly concrete	
Effect of Sugarcane Molasses on Compressive Strength and Workability of Fly Ash Mixed Concrete	0.1%, 0.15%, 0.2%, & 0.25%	Linear increase in slump value with increase in molasses dosage	(Bhide et al. 2017)
		With 0.15% dosage a maximum of 43.9% increase in compressive strength @ 28 days	
		Only 2-5% increase in compressive strength for all specimens @ 56th day	
		Compressive strength decreased by 3.93% @ 56th days with 0.25% (increasing the dosage beyond 0.2% is not desirable)	

Durability of recycled aggregate concrete modified with sugarcane molasses	0.01%, 0.05%, 0.1%, 0.5%, & 1%	0.1–1% dosage accelerates the setting & reduces the standard consistency	(Ali and Ali 2019)
		Significant improvement in workability @ 0.5% and 1%	
		Maximum improvement in compressive strength with 0.5% molasses at 28 and 90-days	
		WA significantly reduced at 0.1% and 0.5% molasses	
Application of cane molasses as concrete retarder admixture (C-25)	0.025%, 0.05%, 0.075%, 0.1%, 0.15%, 0.2%, & 0.3%	Workability increases proportionally as the molasses %age increases	(Kassa 2019)
		From 0.05 to 0.075% gives a favorable maximum delay of initial setting time	
		Reduced compressive strength dev't @ early ages	
		The highest strength development throughout all its age (7th, 14th, & 28th days) with 0.1% dosage ; 25.4 MPa, 30.12 MPa, & 33.92 MPa respectively	
Attribution of molasses dosage on fresh and hardened performance of recycled aggregate concrete	0.25%, 0.5%, & 0.75%	Increased workability @ 0.25%	(Rashid et al. 2019)
		Delayed Initial and final setting @ 0.25	
		Maximum increase in compressive strength with 0.25% molasses at 7, 28 and 365 days	
Effect of Molasses and Water – Cement Ratio on Properties of Recycled Aggregate Concrete	0.25%, 0.50%, & 1%	Workable concrete	(Ali et al. 2020)
		Fresh density increased by > 2.3% from 0 to 1% dosage	
		Maximum compressive strength (13%) with 0.25–0.50% @ 28 day	
		Lower compressive strength with 1% @ 28th day	
		Maximum WA reduction (14%) with 0.5% dosage @ 90 days	

From the summary table 2.5 above, it can be seen that a molasses dosage ranging from 0.01% to 1% with optimum dosage varying mainly from 0.1% to 0.15% has been utilized in which the fresh and hardened properties of C-25 concrete were found to be enhanced. Moreover, it is depicted in the table that, the works of many researchers found to promote the use of molasses as a water reducing plasticizer and retarding admixture in concrete production.

Having found that the investigations so far have been focused on the production of C-25 concrete, the current study utilized molasses as an admixture with a dosage of 0.1%, 0.15%, and 0.2% to investigate the Physio-mechanical and Micro-structural properties of C-30 HVFAC with the aim of promoting the application of molasses in mass concrete structures.

In this study, the decision in molasses dosage was made with the consideration of the previous studies plus to account for the variation in properties of molasses based on the type of soil on which the source cane has grown, the type and condition of the cane, climatic condition and processing of the cane.

2.6 Modern Concrete

Nowadays, concrete is recognized as one of the most important construction materials widely and extensively used in structures, justifying efforts to improve its properties such as compressive and tensile strength. One area of research for this purpose is the use of industrial waste products disposed into the environment by a rising number of industrial establishments the world over (Keshavarz and Mostofinejad 2019).

Modern engineering technologies aim at producing ultra-high performance multifunctional concrete materials due to the increased demand for sustainability, durability and cost-effectiveness. Such construction materials are characterized by improved mechanical properties and long-term performance. They also integrate properties that encourage multiple applications making them sustainable for future uses (Makul 2020). Mineral additives and chemical additives are the part of the modern concrete (Sathyan and Anand 2019). Strength, workability and durability of concrete are the major aspects that are considered in the construction field. These properties are therefore predominantly achieved through many of the recent advancements in the concrete technology. Hence, a HVFAC that utilizes high amount of industrial by-product (Coal fly ash) incorporating a natural admixture (sugarcane molasses) can be considered as a typical reflection in this regard.

2.6.1 High Volume Fly Ash Concrete and Its Properties

The term High-Volume Fly Ash concrete (HVFA) was proposed by Malhotra in 1980s. It is defined as concrete containing 50% or more FA by weight of total cementitious materials (Zhao et al. 2019). According to the definition of HVFA, the FA should be 50% or above by mass of cementitious materials and the concrete should be made with a low water-cementitious materials ratio (w/cm) to achieve the properties required for structural application (Yoshitake et al. 2013). The use of HVFAC has recently gained popularity as a resource-efficient, durable, cost-effective, sustainable option for many types of Portland cement concrete (PCC) applications (Crouch et al. 2007). Any concrete containing a FA content that is greater than 50 percent by mass of the total cementitious materials is considered HVFA PCC. HVFA concrete generally has 50% or more of FA by mass of the cementitious material (cement + FA) and water content less than 130 kg/m3 (Kumar et al. 2007).

Hence, OPC concrete can be replaced with HVFAC that has a FA replacement ratio of at least 50%. Furthermore, HVFAC can be a more environmentally friendly and sustainable material than OPC concrete with a cement replacement by FA of 50% or higher. Following this, in the current study, the FA content of 40%, 50%, and 60% by weight of cement was used in which the 40% FA (which is lower than the minimum percentage of HVFA) was utilized to account for some uncertainties that might result from the variations in the nature of the coal FA from source to source.

In an experimental study done by Z. Zhao et al. (2019), it was revealed and reported that in comparison with PCC, HVFAC exhibits the following properties and benefits:

- Excellent workability,
- Desirable setting time,
- Much lower adiabatic temperature rise,
- Moderate strength at early age,
- Superior strength at later age, and
- Extended durability for a wide range of field applications.
- In addition, use of HVFA provides significant environmental and economic benefits, such as reductions in CO_2 emissions and energy savings.

2.6.1.1 Physio-Mechanical Properties of Concrete with FA

A. Workability

FA has plasticizing properties that improve the workability of the composites. Lee et al. (2018) reported the subsequent factors as possible reasons for FA's plasticizing effect. Firstly, increased composite volume due to FA's lower density than cement. Secondly, FA decreases the flocculation of cement grains because of the dilution effect. Thirdly, the slower reaction rate of FA reduces hydration product growth at the initial time. Besides these causes, the spherical shape of FA grains facilitates the movement of nearby particles by the ball bearing effect, particularly at high replacement levels. Thus, FA can be a more cost-effective method with a low environmental effect to increase the workability than chemical superplasticizer (Mohamed and Khallaf 2022).

B. Unit Weight

Based on unit weight, concrete can be classified into three broad categories. Concrete containing natural sand and gravel or crushed-rock aggregates, generally weighing about 2400 kg/m^3 is called normal-weight concrete, and it is the most commonly used concrete for structural purposes. For applications where a higher strength-to-weight ratio is desired, it is possible to reduce the unit weight of concrete by using natural or pyro-processed aggregates with lower bulk density. The term lightweight concrete is used for concrete that weighs less than about 1800 kg/m^3. Heavyweight concrete, used for radiation shielding, is a concrete produced from high-density aggregates and generally weighs more than 3200 kg/m^3 (P. Mehta and J. Monteiro 2014) which conforms with the classification as per ASTM C330 too.

After an experimental study carried out, by Popovics (2016), to investigate the effects of cement content, air content, slump, aggregate grading and specific gravities on the unit weight of fresh and hardened concrete, it was concluded that the main factor that influences the unit weight of a concrete is the specific gravity of the mineral aggregate, but the effect of the air content is also significant. It was also reported by Abdela and Pandey (2015) that the higher the specific gravity the higher the proportions of concrete. As a result, the specific gravity is considered the main factor for determination of the quality and weight of concrete. In their findings, it was observed that, for a fixed water-to- cement ratio, as the specific gravity of aggregate decreases the unit weight (density) of concrete decreases too. Consequently, a concrete in which cement is replaced with FA (that has a lower specific gravity than cement) in a considerably higher percentage, could have a unit weight less than that of the conventional concrete; the case of the current study.

C. Compressive Strength

Chindaprasirt et al. conducted a thorough investigation to examine the effect of the fineness of FA on the composites' properties; they reported that using finer FA resulted in an increase in Compressive strength. It was discovered that coarse FA is less reactive and needs extra water, producing a more porous mortar. The detrimental effects of coarser FA are described as a cause of decreased strength. Numerous findings have indicated that the application of FA impairs the early-age strength development of composite; however, FA generally enhances the strength and durability of composites over time, as it consumes the $Ca(OH)_2$ produced during the hydration of cement and makes secondary hydrates, for example, CSH.

The quantity of FA used as cement replacement in composites also affects their properties. Barbuta et al. (2019) observed a decrease in compressive strength with the use of FA, and a higher quantity of FA as cement replacement resulted in greater loss of compressive strength. The samples without fibers showed a decrease in compressive strength by 11.3%, 30.4%, 24.8%, 33.7%, and 59.7%, with FA content of 10%, 15%, 20%, 30%, and 40%, respectively, related to the controlled sample. It was also reported that the compressive strength of composites containing higher contents of FA was improved at a later age (1 year) compared to the controlled sample because of the slow pozzolanic reaction (Mohamed and Khallaf 2022).

D. Water Absorption

Use of FA in concrete is beneficial for its pozzolanic property which enhances the durability of concrete. It is used in PCC to improve the concrete performance. When FA particles combines with water and free lime present in the cement matrix, produce additional cementitious materials (pozzolanic activity of FA) which results in denser and higher strength concrete. It also minimizes water demand and reduces bleed channels which increase concrete density. These factors produce concrete of low permeability with low internal voids and hence its durability is also increased. The reduction of permeability also helps to prevent sulphate penetration through the concrete and increases the resistance to corrosion. The pozzolanic reaction between FA and lime produces less heat and therefore reduces the possibility of thermal cracking when FA is used to replace Portland cement (Gorai 2018). Therefore, the use of FA in concrete increases its durability by reducing permeability through the particle packing effect, pozzolanic reactions, and reduced water requirements.

The addition of FA also enhances the durability performance of cementitious composites. Water absorption (WA) is a feature of cementitious materials that are directly associated with its durability or long-term behavior. The existence of pores, cracks, and fissures in the matrix increases WA, which influences the mechanical and other durability aspects. In general, an increase in WA associated with an increase in FA indicates an increase in the volume of accessible pores. Pitroda et al. (2020) concluded that when 10% FA is replaced with cement, the WA of concrete decreases. Additionally, they discovered an increasing trend in WA as the level of cement replaced by FA increased by more than 10%. The WA of FA-incorporated concrete, on the other hand, was found to be greater than those of conventional concrete.

In contrast, Hatungimana et al. noticed a reduction in the WA of concrete with FA addition. They reported that WA values increased as the amount of FA substitution increased, probably because the 28-day curing period was insufficient to complete the pozzolanic reaction; however, at 10% and 20% FA content, the WA of the samples was reduced by 14.6% and 12.2%, respectively, compared to the control mix. Whereas at 30% FA content, the FA concrete sample exhibited a comparable WA capacity to that of the control mix. Finally, the results indicated that FA could be employed as an SCM with some prudent engineering judgments (Mohamed and Khallaf 2022).

2.6.1.2 Micro-Structural Properties

Properties of engineering materials are governed by their microstructure. Compared to other engineering materials like steel, plastics, and ceramics, the microstructure of concrete is not a static property of the material. This is because two of the three components of the microstructure, namely, the bulk cement paste and the interfacial transition zone between aggregate and cement paste change with time (P. Mehta and J. Monteiro 2014).

A. Scanning Electron Micro-Scope (SEM)

SEM is a visual device utilized to magnify concrete cracks and fractures or analyze the materials that are not distinguishable using an optical microscope. SEM is considered an innovative method to comprehend the influence of FA on the morphology of the paste (Amran et al. 2020).

In a study done by Gao et al. (2018) on utilization of beet molasses as a grinding aid in blended cements, the pastes prepared from molasses or triethanol- amine-based grinding aid (TA) cements appeared to have a denser microstructure. Furthermore, as molasses was added in the blended cement, obvious pozzolanic reactions happened around the better grinded GBFS particles. Several FA particles with a dissolved surface or a covering layer of pozzolanic reaction products were observed in this paste indicating an increased pozzolanic reactivity when molasses was added. No typical portlandite crystals were found in this paste. On the other hand, a denser and interconnected network of needle-like hydrates formed in the molasses cement paste.

B. X-ray Diffraction (XRD)

XRD is applied to identify qualitatively the FA crystalline phases. XRD works by using electrons to hit the solid sample which then emits x-rays. Once hitting a crystal structure, different behavior for the x-rays can be examined. Some diffract based on the crystallinity of the structure; however, other types of x-rays will perforate deep inside the sample up to colliding with a crystal. The X-ray instrument scan angles of scattered and diffracted patterns as well as measuring their intensities to create a pattern. A diffractogram is constructed by plotting the produced patterns to link diffraction angle to diffracted intensity (Alterary and Marei 2021). In XRD, the XRD device shoots X-rays that assist with the identification of minerals and other crystalline materials. XRD is also beneficial for determining fine-grained materials, such as FA or cement. XRD is a significant method for quantitatively and qualitatively analyzing cement pastes and cement (Amran et al. 2020)

Surface abrasion resistance of HVFAC modified by graphene oxide (GO) was studied by Du et al. (2020). XRD patterns of OPC and HVFA mixtures were presented and the main phases identified were crystalline quartz (SiO_2) and mullite ($Al_6Si_2O_{13}$) as well as semi-crystalline C–S–H in both OPC mixture and HVFA mixtures with or without GO. It was discussed in their report that at early age (7 days) HVFA mixtures feature a lower intensity of C-S-H peaks compared with that of OPC mixture. This could partially explain why lower compressive strength and surface abrasion resistance were obtained in HVFACs. However, XRD patterns of HVFA mixtures showed a greater trace of C–S–H when GO was admixed into the mixture.

Table 2.6: Summary of some reviewed works on High Volume Fly Ash Concrete

Study Title	FA used (in % by weight of cement)	Main Findings	References
Evaluation of Properties of High-Volume Fly-Ash Concrete for Pavements (@ 7, 28, 90, 180, 256, & 365 days)	20%, 30%, 40%, 50%, & 60%	50–60% FA fulfill the requirement of strength and workability suitable for cement concrete pavement construction	(Kumar et al. 2007)
		F40 developed the highest strength of 83.31 MPa at 90 days and 94.45 MPa at 365 days	
		Maximum increase in compressive strength @ 365 days with 50% FA (95.5%)	
		Least shrinkage with 60% FA	
Tensile properties of high volume fly-ash concrete with limestone aggregate	50%	Uniaxial tensile strength of the HVFA concrete higher than the splitting tensile strength	(Yoshitake et al. 2013)
		The tensile Young's modulus for HVFA concrete was found to be greater than the compressive moduli by as much as 20%	

		40% reduction in the temperature rise	
Creep and thermal cracking of ultra-high volume fly ash (HP-HVFA) mass concrete at early age	F80 (80%) with w/b (0.26) and F35 with w/b (0.43)	Higher slump & delayed setting time with F80	(Zhao et al. 2019)
		The compressive strength of F80 was slightly lower than F35 at 3d and 7d, but higher at 28d and 90d, and almost the same at 180d.	
Performance investigation of high-proportion Saudi-fly-ash-based concrete (@ 3, 14, 28, 56, 91 day, and 1year)	10%, 20%, 30%, 40%, and 50% (Class C ash)	Delayed setting time	(Amran et al. 2020)
		Incessant and considerable development of compressive strength observed after 28 days with 50%	
		Between 14.62% and 29.43% compressive strength enhancement from 28 to 56 days	
		Between 20.75% and 38.49% compressive strength enhancement from 28 to 91 days	
		Between 32.78% and 43.45% compressive strength enhancement from 28 days to 1yr	
Surface abrasion resistance of high-volume fly ash concrete modified by graphene oxide : Macro-and micro-perspectives (@ 28 day)	60% (class C)	Increased compressive strength at the macro level	(Du et al. 2020)
Effects of activator dosage and silica fume on the properties of Na_2SO_4 (Ns) - activated high-volume fly ash (at 1, 3, 7, 35, and 56 days)	70% and 80%	Improved flowability	(Yang et al. 2021a)
		High-dose Ns in HVFA results in faster setting	
		Improved compressive strength by about 20% @ 28 day with 70%	
		Enhanced durability	

Table 2.6 above provides valuable insights into the existing literature associated with FA-based concrete. It reveals that the use of FA in concrete ranges from 10% to 80%, with the majority falling within the 10% to 50% range and very few 60% to 80% even when chemical activators are employed. This variation highlights the flexibility and potential of FA as a SCM. Moreover, it is noteworthy that predominantly calcareous or class-C FA was utilized. The inconsistent strength results observed at different curing periods suggest that the curing duration plays a crucial role in the development of HVFAC's mechanical properties. Additionally, the variations in the optimum percentage of FA indicate the importance of tailoring mix proportions to specific project requirements. Interestingly, all the studies in the table focused on C-25 grade concrete, providing a benchmark for the current study.

Hence, the current experimental study's choice of using 40%, 50%, and 60% FA in C-30 concrete is well-justified based on the following benchmarks. Firstly, the definition of HVFAC as concrete containing 50% or more by weight of total cementitious materials supports the decision to use 50% and 60% FA, aligning with the industry standard for HVFAC. This choice showcases the exploration of the high-volume potential of FA in concrete mixtures. Secondly, incorporating 40% FA recognizes the wide variation in the chemical and physical properties of FA due to factors such as coal source, type of coal burnt, boiler conditions, and pre-combustion processes. By including 40%, it can be able to acknowledge the importance of accommodating different FA sources and characteristics in the current study, thereby enhancing its practical applicability and robustness. In essence, the selection of these FA percentages reflects a comprehensive investigation into the use of FA in C-30 concrete, considering both industry standards and the variability in FA properties.

2.7 Economic and Environmental Aspects of High Volume Fly Ash Concrete

The increase in the demand for concrete production leads to the depletion of virgin concrete ingredients, which is a critical issue for all stakeholders of the CI for sustainable economic growth, particularly in developing countries. Therefore, there is a need to provide further attention to construction materials with regards to the economy, wise energy utilization, and environmental protection for sustainable development (Warati et al. 2019). Cement is one of the ingredients of concrete that needs to get considerable attention in the production of green concrete. The main purpose of reuse of this solid waste material (fly ash) is to minimize the environmental pollution which can occur from its disposal. Instead of this, there are also some other reasons for its utilization: (i) there may be some economic gain from the sale of the by-products, (ii) the by-products can replace some scarce or expensive natural resources, (iii) disposal costs can be minimized, etc. (Gorai 2018).

2.7.1 Economic Feasibility of HVFA Concrete Incorporating Molasses

The overall cost of concrete is made up of the cost of materials, plant and labor (Muritala et al. 2013). The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, hence, the aim is to produce mix using the least quantity of cement required in producing desired strength. Technically, lower cement content results in lower heat of hydration and hence reduces shrinkage cracks while rich mixes may result in high shrinkage and cracking in the structural concrete. Muritala et al. (2013) further elaborated that Concrete is used in all fields of civil engineering. A reduction in the cost of concrete automatically translates into reduction in cost of civil engineering projects without compromising quality.

The continual and increasing needs for infrastructural development in developing countries like ours is putting pressure on the production and supply of cement. Furthermore, as per a study, from the direct cost perspective, using FA reduces costs in concrete production and in FA disposal. Additionally, a more durable concrete also results in long-term costs savings over the lifecycle. Despite the reported benefits of using FA in concrete, the use of FA in the industry is only approximately 25 % of the FA world production (Rivera et al. 2015). Hence, increasing the utilization volume of FA in concrete production beyond 25% or 30%, might be another alternative that has to be sought to magnify the benefits gained so far.

Molasses is nearly 10 times cheaper than the other plasticizers. Using plasticizer in concrete production increases the cost of the concrete by 10% while the increment rate is 1% by using molasses. Concrete costs are reduced by 3% approximately. This ratio occurs as 2% by considering the cost of molasses (Akar and Canbaz 2016). Low cost and environment-friendly concrete can be produced by using molasses (Pathan 2017).

2.7.2 Environmental Feasibility of HVFAC Incorporating Molasses

Production of cement is estimated to account for about 7% of anthropogenic CO_2 emissions, thus contributing significantly to climate change. Approximately 2/3rd of the CO_2 emissions are process related, originating from the conversion of limestone, $CaCO_3$ to CaO and CO_2, while the remaining 1/3rd comes from the combustion of fuels in the rotary kiln of the cement plant. The cement industry can reduce its specific CO_2 emissions through a variety of different techniques, such as increased energy efficiency, utilization of alternative fuels, application of alternative raw materials, and reduction of the clinker to cement ratio (Gardarsdottir et al. 2019). With a FA replacement of cement by 50% or more, HVFA concrete can be a more sustainable and environmentally friendly material than OPC concrete (Du et al. 2020).

According to Z. Zhao et al. (2019), compared with conventional PCC, HVFAC provides significant environmental and economic benefits, such as reductions in CO_2 emissions and energy savings. The massive escalation in the rate of development and expansion due to the increase in economy and population has made concrete as the highest consumer of natural resources. Hence, concrete industry utilizes an enormous volume of natural resources resulting in significant energy usage and economic instability. This also has a negative influence on the environment, which should be mitigated to produce environmentally and economically sustainable CI (Rashid et al. 2019).

2.8 Research Gap

The literature review reveals an omission of key viewpoints regarding the combined effect of HVFA replacement percentages and molasses dosages on the physio-mechanical and micro-structural properties of concrete, specifically in the context of mass concrete structures in hot areas where DEF is a concern. While there is existing research on the individual effects of FA and molasses on concrete properties, there is a lack of comprehensive studies that explore the synergistic effects of varying FA replacement percentages and molasses dosages. Understanding the combined impact of these factors is crucial for optimizing the performance of HVFAC in mass concrete structures.

A notable gap also exists due to the insufficient attention given to the effect of different grades of concrete on the physio-mechanical and micro-structural properties of HVFAC incorporating molasses as an admixture. Previous studies have focused on C-25 concrete, and there is a need to investigate the effect of FA and molasses on higher grades of concrete, such as C-30, which are commonly used in mass concrete structures.

Furthermore, the current literature lacks sufficient analytical focus on the investigation of the long-term durability and sustainability of HVFAC incorporating molasses as an admixture. While the physio-mechanical and micro-structural properties are important indicators of the immediate performance of the concrete, it is crucial to understand how these properties evolve over time and whether the inclusion of molasses has any long-term effects on the durability and sustainability of the HVFAC.

By investigating the combined effects of FA replacement percentages (40%, 50%, and 60%) and molasses dosages (0.1%, 0.15%, and 0.2%) on the physio-mechanical and micro-structural properties of concrete, the research can provide valuable insights into the optimal mix design for achieving desired properties in mass concrete structures. This research gap highlights the need for a comprehensive study that considers multiple variables to address the specific challenges associated with DEF in hot areas.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The literature review in the previous chapter has discussed various past studies and research gaps in relation to HVFAC incorporating admixtures. Based on the identified research gaps, Chapter 3 outlines the research objectives set for this study. This chapter elucidates the methodology adopted to accomplish the study's objectives. This experimental research was mainly focused on laboratory investigations. Based on the necessary material specifications, various standards, and methods, this chapter discussed the methods and materials used to carry out the study. Thus, the necessary procedures to conduct each tests leading to the achievement of the goal of the study were laid and the physical and chemical characterizations of the materials were also discussed prior to the mix design. The pictorial representation of various steps used in the achievement of various objectives is depicted in Figure 3.2.

3.2 Materials Used

In order to evaluate the workability, compressive strength, durability, and microstructure of concrete using different percentages of FA as a cement replacement and molasses as an admixture, materials used in the laboratory for the current study were put through physical and chemical tests so as to ensure that their physical and chemical qualities met the requirements set out by the standards.

3.2.1 Cement

The experiment was conducted using locally available ordinary Portland cement (OPC), which holds the aggregate together when it reacts with water. Because of its superior mechanical qualities, early stripping, and high-grade cement, OPC is widely employed. The chosen OPC with 42.5N Strength Class was obtained from local shops in Adama, Ethiopia, and it was carefully preserved in an airtight container to protect it from moisture, atmospheric agents, and humidity during the experimental period, which confirms ASTM C150 (2012) standard.

3.2.2 Fine Aggregate

Fine aggregate is a granular material made up of small rock grains that is finer than gravel but coarser than silt. Fine aggregate is sand that passes through a sieve size of 4.75 mm and is retained at 150 microns. It should be free from lumps, organic material, silt, etc. Additionally, it should be robust and durable (Dinku 2002). River sand that had been sieved through a 4.75 mm sieve and retained at 150 microns according to ASTM C33 (2018) was utilized in this experiment.

3.2.3 Coarse Aggregate

The aggregates retained on the 4.75 mm sieve are basically classified as coarse aggregates. The coarse aggregate used to make up the concrete samples in this work consists of crushed gravel, which was collected from a local quarry that confirms the requirements of ASTM C33. Generally, the coarse aggregate used for the experiment should be strong, durable, free from vegetable matter, with less than 5% water absorption, and not sharp and angular as per ASTM C33.

3.2.4. Water

Concrete quality is significantly influenced by water impurities and water content. As a result, the concrete water ought to be free of pollutants and chemicals. The current study made use of potable water that complied with ASTM C1602/C1602M (2006) standard.

3.2.5 Molasses

Molasses with the high solid content sample was collected from Wenji Shewa sugar factory, located in Ethiopia at 110 kilometers distance from the capital city Addis. The total molasses produced per day is approximately 189.65 ton. Sample was extracted directly from the blackstrap molasses storage container and to avoid spoil and contamination due to atmospheric air and water, the molasses transported by covering with plastic containers as illustrated in Figure 3.1.

Figure 3.1: Wenji Shewa Sugar Factory molasses Bulk Tanker and Molasses Sample

3.2.6 Fly Ash

Fly ash for this research was sourced from Ayka Addis Textile industry, Ethiopia located at Alemgena, Oromia. The material is available as a by-product of the electric power generation plant. Ayka Addis Textile factory uses local coal which is extracted and supplied from the Achebo area. Complete silicate analysis of fly ashes was conducted at the Geological Survey of Ethiopia in the Geochemical Laboratory and the report of the analysis result was indicated in [Appendix D].

3.3 Research Methods

In material research, a method is a logical, well-organized plan for conducting experimental investigations. The current study employed an experimental method to achieve the aim of the research. To achieve the aim of the current study, different laboratory tests were conducted according to different standard procedures. The outcomes of the tests were quantitatively and qualitatively analyzed based on the standard requirements or specifications. The study also used analytical methods to examine the cost and environmental performance of concrete mixtures in addition to experimental methods. Origin Pro 2023b, X'pert high score plus and Excel software were used to analyze experimental test results. The results of the analysis were presented in the form of tables, graphs, and charts. Figure 3.2 illustrated the research methodology flow chart of the current study.

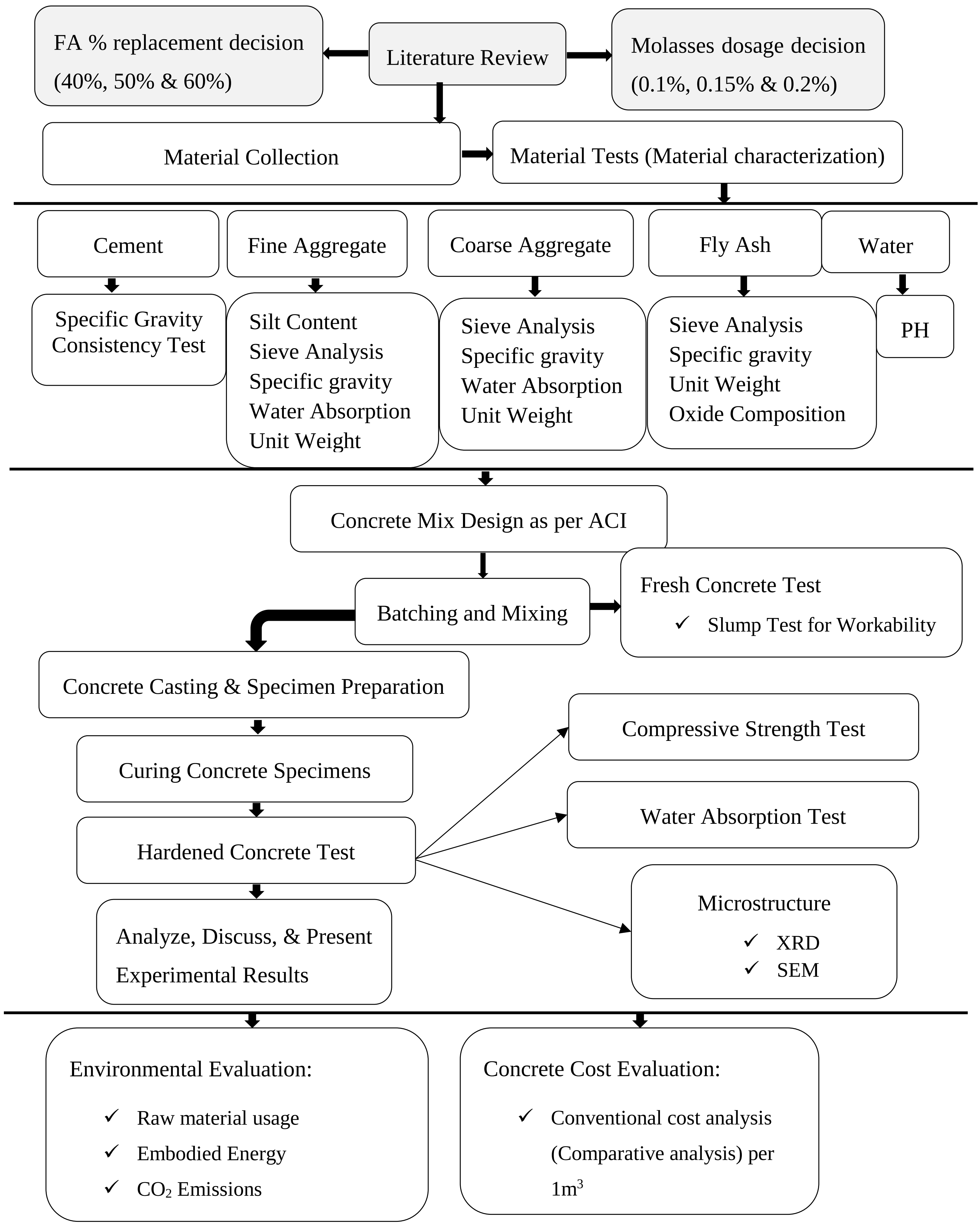

Figure 3.2: Schematic diagrams for research methodology

3.3.1 Tests on Fine Aggregate

3.3.1.1 Silt Content of Fine Aggregate

Silt is a fine material, which is less than 150 microns. Clay, silt, loam, and dust are commonly found in sand. The presence of such materials in sand used to make concrete or mortar decreases the bond between the materials to be bound together and hence the strength of the mixture and long-term durability (Dinku 2002). As a result, testing the silt content of sand and comparing it to acceptable limits is critical. Finding out how much silt was in the sand was the main objective of this test. This test was carried out according to ASTM C 117 (2017) standards. For this experiment, sample sand, clean water, a graduated jar, a spoon, a dish for taking a sand sample, and a funnel were used. The silt content was calculated in accordance of the detailed procedures provided in Appendix B1 and using equation 3.1 below.

$$\text{Silt Content} = \frac{\text{Silt deposited above the sand (A)}}{\text{Amount of clean sand (B)}} \text{ X } 100\% \ldots\ldots \text{Equation 3.1}$$

Figure 3.3: Sand Silt Content Test

Results of the Silt Content test:

For the quality of the mix and to get a better result, the fine aggregate was washed after the silt content measurement to eliminate silt, clay, dirt, and other impurities. According to

Ethiopian standards, silt content should not be greater than 6% (Dinku, 2002). As shown in Table 3.1 which was calculated using Equation 3.1, the average of the three-trial test of silt content of fine aggregate used for this study was 3.5%. The result shows that using this fine aggregate for construction purposes is permissible.

Table 3.1: Silt content test result of fine aggregate

Trial	Volume of separated layer (ml)	Amount of clean sand (ml)	Silt content (%)
1	10	300	(10/300)*100 = 3.33
2	12	300	(12/300)*100 = 4.00
3	9.5	300	(9.5/300)*100 = 3.17
Average	**10.5**	**300**	**(10.5/300)*100 = 3.50**

3.3.1.2 Sieve Analysis of Fine Aggregate

Sieve analysis is a procedure used to assess the particle size distribution of granular material by allowing the material to pass through a series of sieves of progressively smaller mesh sizes and weighting the amount of material that is retained in each sieve as a fraction of the whole mass. Hence, the aim of this test was to determine the fineness modulus of fine aggregate with the help of a series of IS sieves having (4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15, and pan) sizes from top to bottom, respectively, 500 g of fine aggregate, a balance, sieve shaker, shovel, and sieve brush. The test procedure was in accordance with ASTM C136 (2006) and is provided in Appendix B2. The range of Fineness Modulus (F.M.) is between 2.3 and 3.1 (ASTM C33/C33M 2018) and was calculated using Equation 3.2.

Figure 3.4: Fine Aggregate Sieve Analysis Test

$$F.M. = \sum_{n=1}^{7} \left(\frac{\text{Cummulative retained by mass}}{100} \right) \text{…… Equation 3.2.}$$

Fine Aggregate Sieve Analysis Test Results:

The laboratory test was carried out to identify the physical properties of the original sand sample for the determination of particle size distribution or the grading and fineness modulus (F.M.) of the fine aggregate. Table 3.2 and Figure 3.5 illustrate the F.M. of fine aggregate.

Table 3.2: Sieve analysis results and standard for fine aggregate

Sieve Size (mm)	Wt. of Sieve + FA (g)	Wt. of Sieve (g)	Wt. of FA retained (g)	FA retained (%)	Cumulative retained (%)	Cumulative passing (%)	Range (ASTM)
4.75	444	444	0	0	0	100	95-100
2.36	459	404	55	11	11	89	80-100
1.18	562	460	102	20.4	31.4	68.6	50-85
0.6	476	348	128	25.6	57	43	25-60
0.3	497	335	162	32.4	89.4	10.6	5-30
0.15	310	265	45	9	98.4	1.6	0-10
Pan	252	244	8	1.6	-	-	0
Total cumulative percentage retained by mass					287.2		

The F.M. of the fine aggregate used which was computed by using Equation 3.2 is 2.87. The result indicated that it is in the range specified by ASTM C33 (2003) which is from 2.3 to 3.1. The gradation curve of the fine aggregate was laid between ASTM lower and upper limit as seen from Fig. 3.5. So the fine aggregate used was meted the ASTM C136 (2006) requirement.

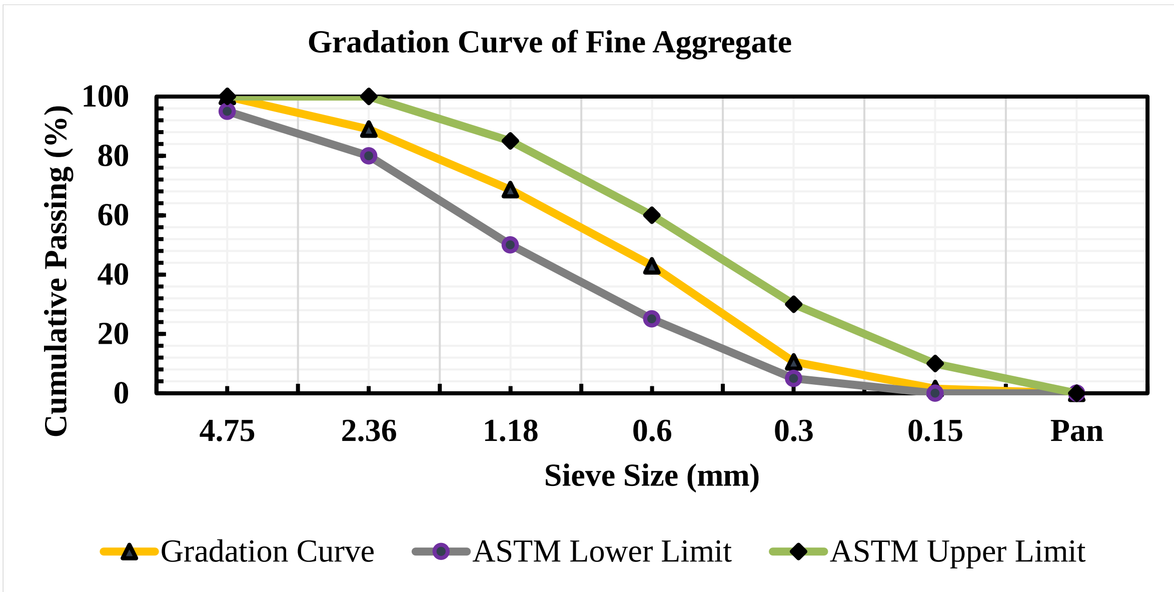

Figure 3.5: Gradation Curve of Fine Aggregate

3.3.1.3 Specific Gravity and Water Absorption Tests of Fine Aggregate

Specific gravity (Relative density) is the ratio of mass of an aggregate to the mass of a volume of water equal to the volume of the aggregate particles – also referred to as the absolute volume of the aggregate, and it indicates how much heavier the material is than water. The difference between the weight of the aggregate in the surface-dried saturated state and the weight of the oven-dried aggregate is used to calculate the water absorption of an aggregate. The density of fine aggregate varies depending on whether it is wet, dry, or loose. ASTM C128 (2015) standard was followed to undertake specific gravity, and water absorption tests for fine aggregate in this experiment. These experiments were carried out using a balance, Pycnometer, pan, shovel, spoon, oven, cone, tamper, and 1000g of fine aggregate sample. The tests were conducted in accordance of the detailed ASTM C128 provided in Appendix B5. The range of specific gravity is 2.5–3 (ASTM C128).

Accordingly, Bulk specific gravity, apparent specific gravity and absorption capacity of fine aggregate were computed through 3.3 to 3.5 equations.

$$\text{Bulk specific gravity (Bsg)} = \frac{S}{(S+B-C)} \text{ ....Equation 3.3}$$

$$\text{Apparent specific gravity (Asg)} = \frac{A}{(B+A-C)} \text{ ....Equation 3.4}$$

$$\text{Absorption capacity} = \frac{S - A}{A} * 100 \text{..................Equation 3.5}$$

Where,

A: Weight of oven dry specimen in air (g).

B: Weight of Pycnometer filled with water (g).

S: Weight of saturated surface dry specimen (g).

C: Weight of Pycnometer with specimen and water to calibration mark (g).

Consequently, Specific gravity and water absorption of fine aggregate were computed through obtained test results. Bulk specific gravity, apparent specific gravity and water absorption of fine aggregate were 2.54, 2.67 and 3.31 respectively which were determined using Equations 3.3, 3.4, and 3.5, as shown in Table 3.3 and all the values were consistent with the (ASTM C128) range.

Table 3.3: Specific gravity and absorption capacity of fine aggregate

Parameters	A	B	C	S	Result
Bsg	-	1462	1765	500	**2.54** (Equation 3.3)
Asg	484	1462	1765	-	**2.67** (Equation 3.4)
Absorption (%)	484	-	-	500	**3.31** (Equation 3.5)

3.3.1.4 Unity Weight Test

The unit weight of fine aggregate is the weight of the sand that is required to fill a container of a specified unit volume. It depends on a variety of factors, including wet, dry, and loose conditions. The test was conducted by using a metal cylinder with a diameter of 100 mm and a height of 175 mm, a tamping rod, and balance. An empty cylinder was weighed and recorded to conduct this test. The cylinder was then filled with fine aggregate in three layers, each of which was tamped with 25 strokes by a tamping rod. The weight of the fine aggregate-filled cylinder was then measured and recorded. Finally, the unit weight of fine aggregate (UWFA) was calculated through equation 3.6

$$UWFA = \frac{F - E}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{ Equation 3.6}$$

Where,

E: weight of empty cylinder (kg)

F: weight cylinder filled with fine aggregate (kg)

V: volume of cylinder ($V= \pi d^2 h/4$), while d is diameter and h denoted height of Cylinder

Unit weight of fine aggregate was computed through the obtained test results by using Equation 3.6 and the result shows that the unit weight of fine aggregate was 1,424 kg/m3 (Table 3.4). Therefore, the computed unit weight of fine aggregate was within the range (1200 to 1750) kg/m3 that specified by ASTM C29.

Table 3.4: Calculation for the Unit Weight of Fine Aggregate

F(kg)	E(kg)	(F – E) (kg)	V (m^3)	UWFA (kg/ m^3) (Eq. 3.6)
6.692	4.734	1.958	0.001375	**1424**

3.3.2 Tests on Coarse Aggregate

3.3.2.1 Sieve Analysis of Coarse Aggregate

The coarse aggregate obtained from the local quarry should be tested against gradation to determine its particle size distribution. The main aim of coarse aggregate grading is to determine the fineness of the aggregate and to identify the category of aggregate used for the test. Gradation is determined by passing the material through a series of sieves stacked with progressively smaller openings from top to bottom and weighing the material retained on each sieve. From top to bottom, the IS sieves are 20 mm, 19mm, 12.5 mm, 9.5 mm, 4.75 mm, and pan, respectively. Because the material that passed through the sieve opening 4.75mm was initially excluded, aggregates less than 4.75 mm were not used. Sieve analysis apparatus used for the current study includes a set of IS sieves, a pan, shovel, balance, a mechanical sieve shaker, and a sample splitter. The test was undertaken according to ASTM C136 (2006) standard with a detailed procedures provided in Appendix B3. The range of fineness modulus of coarse aggregate according to ASTM C33 is **5.5 – 8.0.**

$$\text{F.M.}=\sum_{n=1}^{11}\left(\frac{\text{Cummulative retained by mass}}{100}\right)\text{............Equation 3.7.}$$

Coarse Aggregate Sieve Analysis Test Results:

The grain size distribution of the coarse aggregate and its grading requirement according to ASTM C136 (2006) is as show in Table 3.5.The fineness modulus of coarse aggregate was computed by using Equation 3.7. The result indicated that the fineness modulus of the coarse aggregate was 7.15 which was found to be within the range of the (ASTM C33) standard.

Table 3.5: Sieve Analysis of Coarse Aggregate

Sieve Size (mm)	Wt. of Sieve + CA (g)	Wt. of Sieve (g)	Wt. of CA retained (g)	CA retained (%)	Cumulative retained (%)	Cumulative passing (%)	Range (ASTM)
20	1297	1297	0	0	0	100	100
19	494	436	58	2.9	2.9	97.1	90 - 100
12.5	1,135	440	695	34.75	37.65	62.35	50 – 80
9.5	1,170	445	725	36.25	73.9	26.1	20 – 55
4.75	969	447	522	26.1	100	0	0 - 10
Pan	250	250	0	0	0	0	-
Total cumulative percent retained by mass					**714.45**		

The gradation curve of the coarse aggregate used in this study was within the ASTM lower and higher limits, as shown in Figure 3.6. As a result, the coarse aggregate used met the requirements.

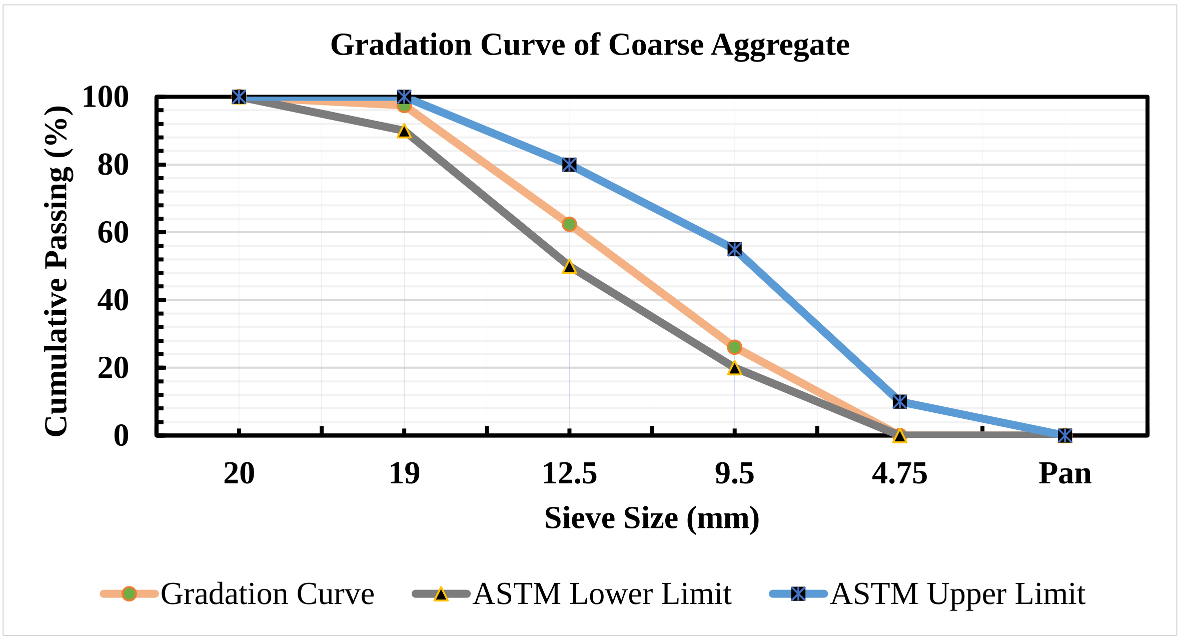

Figure 3.6: Gradation Curve of Coarse Aggregate

3.3.2.2 Specific Gravity and Water Absorption of Coarse Aggregate

Specific gravity is the ratio of a given volume of aggregate to the weight of an equal volume of water. This is a measure of the strength or quality of a particular material. Low-density aggregates are generally weaker than high-density aggregates. The water absorption test determines the water holding capacity of the coarse aggregates. It gives an idea of the internal structure of the aggregate and the strength of the aggregate. The density of coarse aggregate varies depending on the source, nature, and condition, like wet or dry. Apparatus used were balance, a 4.75mm (No.4) sieve, shovel, sample splitter, wire basket or sample container, water tank, absorbent cloth, and oven. Density, specific gravity and water absorption tests were done according to ASTM C127 (2015) standard and Overall calculations were done using equations 3.8 to 3.10. In Appendix B6 of this report, the experimental procedures related to these tests were provided.

$$\text{Bulk specific gravity (Bsg)}=\frac{M}{(M - L)} \text{ ....Equation 3.8}$$

$$\text{Apparent specific gravity (Asg)}=\frac{N}{(N - L)} \text{ ....Equation 3.9}$$

$$\text{Absorption capacity} =\frac{M- N}{N} * 100 \text{..............Equation 3.10}$$

Where,

L: Pycnometer weight with specimen and water to calibration mark (g).

M: Weight of the saturated surface-dry specimen (g).

N: Weight of air-dried oven-dried specimen (g).

Hence, Specific gravity and water absorption of coarse aggregate were computed through obtained test results. Bulk specific gravity, apparent specific gravity and water absorption of the coarse aggregate were 2.61, 2.68 and 1.76 respectively which were determined using Equations 3.8, 3.9, and 3.10, as shown in Table 3.6. The obtained result, for specific gravity of coarse aggregate was between limit (2.5 to 3.0) that specified by ASTM C128. In addition, water absorption of coarse aggregate was less than the specified maximum value (2%).

Table 3.6: specific gravity and absorption capacity of Coarse aggregate

Parameters	L	M	N	Result
Bsg	1850	3000	-	**2.61** (Equation 3.8)
Asg	1850	-	2948	**2.68** (Equation 3.9)
Absorption (%)	-	3000	2948	**1.76** (Equation 3.10)

3.3.2.3 Unit Weight of Coarse Aggregate (UWCA)

The unit weight of coarse aggregate is the weight of the coarse aggregate required to fill a container of a specified unit volume. This test was carried out in the same way that the procedure for determining the unit weight of fine aggregate was carried out in the previous section and was calculated using equation 3.11 below. According to ASTM C29 (2017), the unit weight of aggregate ranges from 1200 to 1750 kg/m^3.

$$UWCA = \frac{G- H}{V} \quad \text{…………………..Equation 3.11}$$

Where,

G: aggregate plus cylinder weight

H: Weight of the empty cylinder

V: Volume of the cylinder (m3)

Unit weight of coarse aggregate was computed through obtained test results as shown in Table 3.7.

Table 3.7: Calculation for the Unit Weight of Coarse Aggregate

G(kg)	H(kg)	(G – H) (kg)	V (m^3)	UWCA (kg/ m^3) (Eq. 3.11)
6.992	4.734	2.258	0.001375	**1642.18**

The result shows that, the unit weight of coarse aggregate was laid between the ranges (1200 to 1750) kg/m3 that specified by ASTM C29. Therefore the coarse aggregate used for the current study was fulfilled the requirements in terms of unit weight.

3.3.3 Water Test

Water is one of the most important components of concrete. Oil, alkali, and acid should not be present in the water used for mixing. Water impurities can affect the strength and lifespan of concrete by preventing it from properly setting. As a result, water quality testing is required. Therefore, determining the pH value of the water is crucial. The pH value determines the quality of the water used in concrete production. For concrete mixing and curing, the pH level should be between 6.5 and 8.5 (ASTM C1602). When the pH falls below 6, corrosion occurs, and when the pH rises too high, concrete loses its binding property and cracks.

The pH value of the water was measured using a pH meter in this study. To carry out this test initial water sample was prepared from water used for drinking function at Adama Science and Technology University. The electrode was then placed in the buffer. The electrode was then inserted into the water sample that had been prepared. Finally, the pH value of water was read from a pH meter. Therefore, according to the result obtained, the pH value of water found at Adama Science and Technology University is 7.56. The acquired result is between the ranges (6.5 to 8.5) that specified by ASTM C1602 (2006) standard. So, the water used for mixing concrete in the current study is fulfilled the requirements.

3.3.4 Tests on Fly Ash and Cement

3.3.4.1 Preparation of Coal Fly Ash

Primarily, the raw FA by-product was collected from the source and packed for transportation and then transported to the laboratory and placed around a clean and dry area. Then, the sample was subjected to sufficient air drying to remove trapped moist air. Following this, the sample was sieved through 150μm sieve size to collect only particles finer than 150μm for further process and remove the coarser one. Finally, the sample was ground and pulverized to a dry and homogeneous ash of 75μm particle size and even finer. Figure 3.7, shows the procedures followed to prepare the FA sample.

Figure 3.7: Fly ash sample preparation process

3.3.4.2 Sieve Analysis of Fly Ash

The main objective of this test is to determine the particle size distribution of FA thereby to check whether the FA fulfil ASTM requirements for pozzolanic materials to be used as SCMs in concrete. Sieve analysis of the FA was undertaken to determine the percentage of fine particles of FA that pass through a sieve opening of 45μm. First, dry sieving of FA was carried out using sieve sizes of 150μm and 75μm. To do so, 100gm of FA was taken and sieved in accordance of the sieve analysis procedures followed for the fine aggregate. As shown in Table 3.8, 87% of FA was passed through opening of 75μm.

Table 3.8: Particle size of cement and FA

Sieve size (μm)	Wt. of sieve (g)	Fly Ash		
		Wt. of sieve + retained (g)	Wt. retained (g)	% finer
150	310	310	0	100
75	275	288	13	**87**
Pan	252	339	87	0
Total			100	

Following the dry sieving the wet sieve analysis for FA was carried out. The wet sieving for the FA was conducted in accordance of ASTM D6913 (2009) general procedures provided in Appendix B4. Following the general procedures, the test result was organized and reported as in Table 3.9 below.

Table 3.9: Wet Sieve Analysis of Fly Ash Through 45micron

Sample	W1 (g)	W2 (g)	W3 (g)	W4 (g)	W5 (g)	W6 (g)	W7 (g)	P (%)
Retained	1364	396	242	154	98	163	65	**32.5**
Passed	1039	397	87	310	95	230	135	**67.5**

W_1 = Wt. of (retained/pass + beaker + water)

W_2 = Wt. of (residue + beaker)

W_3 = Wt. of beaker

W_4 = Wt. of wet residue

W_5 = Wt. of plate for sample drying

W_6 = Wt. of (dried sample + plate)

W_7 = Oven dried sample Wt. ($W_6 - W_5$)

P = percent retained/pass = (W6/200) * 100

As shown in Table 3.9 above, the percentage of the FA retained on sieve 45μm is 32.5 and it is specified in ASTM C618 (2019) that for pozzolans to be used in concrete the amount retained when wet-sieved on 45μm sieve should be less than or equal to 34%. Hence, since the amount of FA retained on no.325, 32.5% is less than 34% of ASTM requirement, the FA has fulfilled the requirement. Therefore, the FA can be used as a SCMs in concrete. Furthermore, the result depicts that more fine FA was utilized and implying FA has a larger specific surface area. This is because as particle size decreases, the surface area of substances increases (Selamawit W, 2020). The specific surface area (SSA) of FA has a significant effect on its pozzolanic reactivity and on the performance of FA-blended concrete (Wang et al. 2018). This implies a reduction in particle size utilized to fill the gap between aggregates. However, an increase in the surface area leads to incremental water needs, which leads to compressive strength reduction and durability degradation when the FA is employed in large amounts.

3.3.4.3 Specific Gravity of Fly Ash and Cement

The density (specific gravity) of hydraulic cement is used in the calculation of the total aggregate content and of the concrete density. The bulk and absolute densities of cement do not differ greatly in practice, since cement is usually well-graded and must be kept dry, and in any case the precise cement density is not critical in mix design. It is therefore reasonable to use the bulk density (Dinku 2002) . With this under consideration, the specific gravity of the cement used in this study was taken to be 3.15 which is within the range of ASTM C188 (2009) standards (from 3.1 to 3.16). Whereas, the specific gravity of FA taken from the same source (Ayka Addis Textile Industry) was done by L.Abebaw and P.Vadivu (2021) and reported 2.13. This implies the FA is lighter than cement which resulted in the reduction in the unit weight of concrete.

3.3.4.4 Unit Weight Test

The density of FA is the weight of the ash that is required to fill a container of a specified unit volume. This test was done to determine the density of FA. The test was conducted by using a metal cylinder with a diameter of 100 mm and a height of 175 mm, a tamping rod, and balance. To undertake this test initial empty cylinder was weighted and recorded, then FA was filled into the cylinder through three layers, and each layer was rodded with 25 strokes by the tamping rod. After that, the weight of the filled cylinder with FA was measured and recorded. Finally, unit weight of FA was computed through equation 3.12.

$$UWFA = \frac{Y - Z}{V}$$ …………………. Equation 3.12

Where,

Z: weight of empty cylinder (kg)

Y: weight cylinder filled with FA powder (kg)

V: volume of cylinder ($V= \pi d^2 h/4$), while d is diameter and h denoted height of Cylinder

Consequently, the unit weight of FA was computed through the obtained test results by using Equation 3.12 and the result shows that the unit weight of FA was 789.82 kg/m^3 (Table 3.10).

Table 3.10: Calculation for the Unit Weight of Fly Ash

Y(kg)	Z(kg)	(Y – Z) (kg)	V (m^3)	UWFA (kg/ m^3) (Eq. 3.12)
5.82	4.734	1.086	0.001375	**789.82**

As a result, unit weight of FA is lower than the unit weight of cement (1440 kg/m^3) which indicates concrete with FA is lighter than concrete without FA.

3.3.4.5 Chemical Composition of FA and National OPC Cement

There are several reasons to undertake chemical composition analyses. The analysis offers useful details about the components of a test sample. Analysis of the sample's chemical composition is done to figure out the amount of different oxides that are present in the sample. Different approaches can be used to conduct this analysis. For this study, the chemical composition analysis result of the same cement (National OPC Cement) reported by Bedaso (2022) which was determined through complete silica analysis at laboratory of the Ethiopian Geological Survey was used and presented in Table 3.11. The results show that the cement is reach in CaO and SiO_2 content, 60.40% and 26.02% respectively.

Whereas, the chemical composition of FA was determined through complete silica analysis at laboratory of the Ethiopian Geological Survey and also presented in Table 3.11. The results show that FA was reach in SiO_2 content (49.34%) and it has high LOI content. The reason for occurrence of high LOI in FA is presence of carbon in the ash due to low combustion temperature. According to Okoya et al. 2021, the value of LOI increases when compounds are burned at a low temperature. The FA has LOI value of 11.14%, which is lower than ASTM C618's maximum value of 12%. The combined oxide composition:

$SiO_2 + Al2O_3 + Fe_2O_3 = 82.89\%$ which is greater than 50%. So according to ASTM standards FA shows the pozzolanic property and belonged to class F pozzolanic materials.

Furthermore, the FA was discovered to contain a low alkali content, such as K_2O (0.62%), signaling a low potential for the alkali-silica reaction when utilized in concrete with silica reach aggregate. As a result, combining FA with silica reach aggregate has less impact on the long-term durability of concrete.

Table 3.11: Percentage Oxide composition of FA and National OPC cement

Oxides	**National OPC Cement [Bedaso. (2022)]**	**Fly Ash [Appendix D]**
SiO_2	26.02	49.34
Al_2O_3	5.09	30.53
Fe_2O_3	3.48	3.02
CaO	60.40	0.14
MgO	1.76	0.24
Na_2O	0.34	< 0.01
K_2O	0.56	0.62
MnO	0.04	< 0.01
P_2O_5	0.1	0.17
TiO_2	0.16	0.67
H_2O	0.19	1.32
LOI	1.89	11.14
SiO_2+ Al_2O_3+ Fe_2O_3	**34.59**	**82.89 > 70**

3.3.5 Tests on Blended Paste

3.3.5.1 Normal Consistency of Cement and Blended Pastes

The normal consistency of hydraulic cement is the amount of water required to make a neat paste of satisfactory workability (Dinku 2002). The normal consistency test is used to determine the amount of water needed for the paste in order to achieve standard consistency or normal consistency. The test was conducted according to ASTM C187(2016) standard to determine the normal consistency of hydraulic cement. As a result, a vicat apparatus was used to determine the typical consistency. The experimental study do contain 10 different cement paste mixes, 1 the control cement paste and the remaining were blended cement pastes with varying content of FA (40%, 50%, and 60% of weight of cement) in combination of varying molasses dosages (0.1%, 0.15% and 0.20%) for each replacement scenario. Therefore, the test was done for ten different paste mix scenarios and was performed according to the instructions in ASTM C 187 which was summarized in paragraph below.

To begin this test, 500 g of cement and water amounting to a percentage of cement (22-30%) were mixed together to make cement paste and the paste was properly combined with in 3-5 minutes. The amount of replacement in the blended paste was subtracted from the total amount of cement in each replacement percentage. Next, the paste was placed properly on the ring of the Vicat apparatus, and excess paste was removed with the help of trowel. After that, the plunger was attached to the moveable rod of the Vicat apparatus, and the movable indicator was seated initial reading could be taken. The rod was released after 30 seconds of paste formed, and the paste shall be of normal consistency when the rod settles to a point 10 mm below the original surface 30 seconds after being released. Lastly, after the trial was made the normal consistency result was obtained. According to ASTM C187 (2016) the percentage of the water to be added to obtain the normal consistency is about 22-30% of the amount of cement and thus the experiment was repeated until the normal consistency was obtained. Appendix E1 shows experimental works during the normal consistency and setting time tests.

3.3.5.2 Setting Time of the Blended Paste

The duration a cement paste requires to undergo setting which is the consequence of hydration is its setting time. The objective of this test is to determine the initial setting time and final setting time of cement paste with normal consistency. Generally, there are two types of setting time to be determined in the laboratory, initial and final setting times. The initial setting is the duration of cement paste related to 25mm penetration of the vicat needle into the paste in 30 seconds after it is released while the final setting time is that related to zero penetration of the vicat needle into the paste (Dinku 2002). Hence, the initial and final setting time of the control and the blended cement pastes were determined using vicat apparatus in conformity with ASTM C191 (2004) following the general procedures described in paragraph below.

Initially, 500 g of cement and 40, 50, and 60 % FA by weight of cement and 0.1, 0.15% and 0.20% molasses by weight of cement were used in the setting time test. Then, using the water content determined during the normal consistency test, cement paste and blended cement paste were prepared. The time since water was added to the cement was recorded after the paste was placed on the Vicat ring. The specimen was allowed to sit for 30 minutes in the moist cabinet after molding without being disturbed. Until the penetration was reached 25 mm, the penetration of 1mm needle was determined for every ten minutes. The initial reading was obtained by lowering the needle of the Vicat apparatus until it met the surface of the cement paste and tightening the screw. After that, the screw was released, and the needle was allowed to settle for 30 seconds to read the penetration. However, the final setting time is computed when the needles do not visibly sink into the paste.

3.3.6 Physio-Chemical Test of Molasses

Secondary data was employed to assess the physio-chemical properties of the molasses utilized in this investigation. Sugarcane molasses that was collected from the same source, Wenji Shewa sugar factory, has undergone the Physio-Chemical test in the study done by Kassa (2019) and the results are as reported in Table 3.12 below. The physio-chemical property of the molasses used throughout the experiment is given in Table 3.12.

Table 3.12: Physiochemical characterization of molasses (Kassa 2019)

Parameters	PH	Ash Content (%)	Brix	Color	Viscosity	Total sugar (%)	FRS (%)	Nitrogen (%)
Values	5.05	10.8	79.5	Dark brown	3042cP @20 °C	46.8±0.37	15.9± 1.07	0.33± 0.04

N.B. FRS stands for Free Reducing Sugar

Brix is a measure of the sugar content in a solution. As indicated in table 3.1, the high Brix value of 79.5 indicates that sugarcane molasses contains a significant amount of dissolved sugars. The presence of high sugar content in molasses can act as a water-reducing agent. Sugars have the ability to disperse and reduce the amount of water required in a concrete mix without compromising its workability. Furthermore, the total sugar content is a key parameter in assessing the potential water-reducing properties of sugarcane molasses. The value of 46.8% indicates that nearly half of the molasses consists of sugars. High sugar content suggests that this molasses could effectively function as a water-reducing admixture. Water-reducing admixtures are used to improve the workability of concrete mixes while reducing the water-to-cement ratio, which can enhance the strength and durability of concrete. - FRS represents the portion of sugars in the molasses that are readily available for chemical reactions. This parameter is particularly important in assessing the retarding properties of molasses. The FRS value of 15.9% ± 1.07% suggests that there is a significant amount of sugars available to participate in chemical interactions. This can lead to retarding effects on the setting and hardening of concrete. Some studies also disclosed that molasses, as a by-product of the sugar plant, has been proven as a type D admixture for Portland cement (Huang et al. 2020).

In summary, based on the high Brix and total sugar content, sugarcane molasses appears to have the potential to serve as a water-reducing admixture, improving the workability and performance of concrete mixes. Additionally, the presence of readily available reducing sugars (FRS) suggests that it may also have retarding properties. Therefore, based on the chemical characteristics discussed above, the molasses can be used as Type D, which are classified as water-reducing and retarding admixtures according to ASTM C494.

3.3.7 Mix Design

Concrete Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the objective of producing concrete of certain minimum strength and durability as economically as possible. The mix ratio depends on the mix design. In this study, ACI method was used to design mix proportion for C-30 grade of structural mass concrete. It involves designing a basic mixture containing only cement as a binder and incorporating Fly Ash in required percentage to produce final batches by adjustment of material quantities per unit volume. Target mean or average compressive strength of C-30 concrete is the sum of characteristic compressive strength at 28 days in N/mm^2 and concrete grade factor.

The amount of cement, fine aggregate, coarse aggregate, and water was determined by the properties of the concrete ingredients and the test results obtained from the ingredients. Based on the mix-proportion of the control-mixes, the fine aggregate-to-total aggregate ratio was fixed as 0.45 for C-30. The amount of water, cement, coarse and fine aggregate was proportioned according to “Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1)” by the following procedures:

Step-1: Selecting slump and the required or target mean 28-day compressive strength

For mix proportioning.

- Convert the 30 MPa cubic characteristic compressive strength to an equivalent cylindrical characteristic compressive strength (using 0.85 conversion factor as per ASTM C42) since the ACI mix design calculation is based on it. Thus, the equivalent cylindrical characteristic compressive strength = 0.85* 30 = 25.5Mpa. Then adding the average compressive strength conversion factors of ACI provided in Appendix A1,the target mean compressive strength (F'ck) = fck +8.5 = 25.5 + 8.5 = **34 MPa**
- For C-30, a concrete slump of 2–10 cm is recommended

Step-2: Choice of maximum size of aggregate

- For higher compressive strength, a reduced maximum size aggregate was selected. In this case, the selected maximum and nominal size of aggregates was 20 mm and 19mm respectively with non-air entrained concrete.

Step-3: Estimation of mixing water and air content

- The quantity of water per unit volume of concrete required to produce a given slump is dependent on: the nominal maximum size, particle shape and grading of the aggregate, the concrete temperature, the amount of entrained air and use of chemical admixtures. The ACI table provided in Appendix A2 provides estimates of required mixing water for concrete made with various maximum sizes of aggregate, with and without air entrainment. Accordingly, with a slump of 2–10 cm and a maximum size aggregate of 20 mm, the water content becomes **185 Kg/m^3** and **2%, or 20 liters** of entrapped air.

Step- 4: Selection of water-cement ratio

- In a concrete mix, the water-cement ratio is the ratio of the weight of water to the weight of cement. The ACI table provided in Appendix A3 cannot provide the exact value of the water-cement ratio for a 34 MPa mean strength. Thus, the exact value was calculated by linear interpolation between the w/c of 30MPa and 35 MPa. As a result, the minimum water cement ratio was obtained to be **0.435**.

Step- 5: Determination of mix cement content

- The amount of cement per unit volume of concrete is fixed by the determinations made in Steps 3 and 4 above. The required cement is therefore equal to the estimated mixing-water content (Step 3) divided by the water-cement ratio as shown below. It is known that, from durability considerations, cement content should not be reduced below 300 Kg/m^3 for concrete. The computed cement content was greater than the specified minimum cement content, which is 300 kg/m^3. Therefore, 425.29 kg/m^3 was used for the mix design for this study.

$$\text{Cement Content} = \left(\frac{\text{Water content}}{\text{Water cement ratio}}\right) = \frac{185\text{Kg/m3}}{0.435} = \mathbf{425.29kg/m3}$$

In this study, the specific gravity of Fly Ash was 2.13, which is less than the cement, 3.15. Therefore, water to cementitious material ratio for different percentage of replacement were different. Water to cementitious material ratio (w/cm) was computed as follows via equation 3.13.

$$\text{w/cm} = \frac{3.15(\text{w/c})}{3.15(1\text{-A}) + \text{sg(A)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 3.13}$$

Where,

- W/cm: water to cementitious material ratio.
- W/c: water to cement ratio for control mix.
- A: replacement percentage.
- Sg: specific gravity of cementitious material (2.13)
- 3.15: specific gravity of cement.

Based on above equation the w/cm for all replacement percentage were determined:

$$\text{For 40\% replacement} = \frac{3.15(0.435)}{3.15(1\text{- }0.4) + 2.13(0.4)} = 0.50$$

$$\text{For 50\% replacement} = \frac{3.15(0.435)}{3.15(1\text{- }0.5) + 2.13(0.5)} = 0.52$$

$$\text{For 60\% replacement} = \frac{3.15(0.435)}{3.15(1\text{- }0.6) + 2.13(0.6)} = 0.54$$

From the above calculation as the percentage of replacement increased the amount w/cm also increased. Hence, since all the results were greater than water to cement ratio of the control mix, that minimum w/c value was used for all mixes.

Step- 6: Estimation of coarse aggregate content per Unit Volume of Concrete

- This depends on the fineness modulus, which is 2.87, and the maximum size aggregate of 20 mm. The ACI table provided in Appendix A4 was referred to do so. Hence, based on the table value and with a slight interpolation calculation between fineness modulus of 2.8 and 3.0 for 20mm maximum size aggregate, the bulk volume of dry rodded aggregate was determined to be 0.62.

Step- 7: Calculate the weight of coarse aggregate (WCA) per m3 of concrete

WCA=bulk volume x bulk density of coarse aggregate = 0.62 x 1642.18

= 1018.15 Kg/m3

Step- 8: Determining the solid volume of coarse aggregate

$$\text{Solid volume of coarse aggregate} = \frac{\text{WCA}}{\text{Specific gravity}} = \frac{1018.15 \text{ Kg/m3}}{2.68} = 379.9 \text{ Kg/m}^3$$

Step- 9: Calculating the solid volume of cement, water, and air

$$\text{Volume of cement (VC)} = \frac{\text{Weight of cement}}{\text{Specific gravity of cement}} = \frac{425.29 \text{ Kg/m3}}{3.15} = 135.01 \text{ Kg/m}^3$$

Volume of water (VW) = 185 Kg/m^3

Volume of air (VA) = 2% or 20 Kg/m^3

Step- 10: Calculating the solid volume of Sand

Solid volume of sand = 1000 -(VCA + VC + VW + VA) =1000 - (379.9 + 135.01 + 185 + 20)

= 1000 - 719.91 = 280.1 Kg/m^3

Solid weight of sand = dry volume of sand x specific gravity =280.1 x 2.67 =747.87 Kg/m3

Step- 11: Adjustments for moisture in the aggregate

Fine aggregate adsorption = 3.31% and coarse aggregate absorption = 1.76%

Water absorbed by coarse aggregate = 1,018.15 kg/m3 x 0.0176 = 17.92 kg/m^3

Water supplied by fine aggregate = 747.87 Kg/m3 x 0.0331 = 24.75 kg/m^3

Therefore, Amount of water needed = 185 + 17.92 - 24.75 = 178.17 kg/m^3

Cement = 425.29 kg/m^3

Fine aggregate = 747.87 + 24.75 = 772.62 kg/m^3

Coarse aggregate = 1018.15 - 17.92 = 1000.23 kg/m^3

Hence, the estimated batch weight for 1 cubic meter of concrete is given in Table 3.13.

Table 3.13: Calculated Batch for 1m^3 of Concrete

Cement	425.29 kg/m^3
Fine Aggregate	772.62 kg/m^3
Coarse Aggregate	1000.23 kg/m^3
Water	178.17 kg/m^3

The mix design ratio can be expressed as in Table 3.14 below based on the above estimated batch weight values.

Table 3.14: Mix Ratio for C-30 Concrete Grade

Ingredients	Cement	Fine aggregate	Coarse aggregate
Amount /m^3	425.29/425.29	772.62 /425.29	1000.23 /425.29
Ratio	1	1.82	2.35

Based on the mix proportion given above, the quantity of each concrete ingredient can be calculated for one cube standard mold.

Wet volume for 1 Mould = length x width x height =0.15m x 0.15m x 0.15m = 0.00375 m3

Dry volume for 1 Mould = 1.54 x wet volume = 1.54 x 0.00375 m3 = 0.0051975 m3

Sum of ratio = $\sum$ ratio = 1 + 1.82 + 2.35= 5.17

$$\text{Weight of cement} = \frac{1}{\text{sum of ratio}} \text{ x dry volume x weight of cement} = \frac{1}{5.17} \text{ x } 0.0051975 \text{ x } 1440$$

$$= 1.45 \text{ kg}$$

$$\text{Weight of FA} = \frac{1.88}{\text{sum of ratio}} \text{ x dry volume x weight of FA} = \frac{1.82}{5.17} \text{ x } 0.0051975 \text{ x } 1424$$

$$= 2.61 \text{ kg}$$

$$\text{Weight of CA} = \frac{2.35}{\text{sum of ratio}} \text{ x dry volume x weight of CA} = \frac{2.35}{5.17} \text{ x } 0.0051975 \text{ x } 1642.18$$

$$= 3.88 \text{ kg}$$

Weight of water= amount of water needed x dry volume = 178.17 x 0.0051975 = 0.926 kg (L)

Since specific gravity of cement and Fly Ash were not equal, 1kg of cement is equal to 0.469 kg (0.5) of FA. Therefore, 1 kg of cement was replaced by 0.5 kg of FA. The mix design for one cubic meter of concrete production was summarized as in Table 3.15. Amount of cement is depend on amount of replacements. While the content of fine and coarse aggregates are the same throughout.

Table 3.15: Summary of Concrete Mix for one Cube Mould

No	Mix ID	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Fly Ash (kg)	Molasses (g)	Water (ml)
1	R	1.45	2.61	3.88	0	0	926
2	M40,0.10	0.87	2.61	3.88	0.58	1.45	926
3	M40,0.15	0.87	2.61	3.88	0.58	2.18	926
4	M40,0.20	0.87	2.61	3.88	0.58	2.90	926
5	M50,0.10	0.73	2.61	3.88	0.73	1.45	926
6	M50,0.15	0.73	2.61	3.88	0.73	2.18	926
7	M50,0.20	0.73	2.61	3.88	0.73	2.90	926
8	M60,0.10	0.58	2.61	3.88	0.87	1.45	926
9	M60,0.15	0.58	2.61	3.88	0.87	2.18	926
10	M60,0.20	0.58	2.61	3.88	0.87	2.90	926
Total		7.99	26.1	38.8	6.54	19.59	9260

N. B. In the above Mix ID representation, R stands for reference or control mix, whereas in the mix ID denoted by M the numbers 40, 50 and 60 represents the percentage replacements of cement by FA (40%, 50%, and 60% of cement by weight respectively) and the numbers 0.10, 0.15 and 0.20 are there to indicate the Molasses dosages used (0.10%, 0.15% and 0.20% by weight of cement respectively).

3.3.8 Batching and Mixing

3.3.8.1 Batching

Batching of concrete is the process of measuring concrete ingredients to get concrete mixtures. For this specific experiment, batching by weight was preferred over volume batching to get a proper mix of concrete ingredients since it is difficult to find the exact volume of granular materials because of their voids. OPC cement was replaced partially by the weight at different percentage by FA. In addition to that, 0 % replacement was used as a control test for the study. Fig. 3.8 (a) shows the batched ingredients ready for mixing.

3.3.8.2 Mixing

Concrete mixing is the process of combining concrete components like cement, fine aggregate, coarse aggregate, water, and other ingredients to get effective and good- quality concrete. In this study, a mixer was used to mix concrete ingredients together to obtain homogeneous, good-quality concrete. The mixing process was started by combining all the weighted ingredients in the mixer except water and the Molasses and dry mixing for 3min as shown in Fig. 3.8(b). Then 50% of the mixing water was added and mixed for another 3min as indicated in Fig. 3.8(c). Finally, the rest of the water was added little at a time to maintain the required slump. In the special-mixes (with molasses) the reserved 50% mixing water was added after being mixed with the molasses solution.

Figure 3.8: Batching and mixing procedures: Batched ingredients (a), dry mixing (b) and wet mixing (c)

In table 3.16, the mix IDs with their corresponding notation meanings are given. Therefore, the 40, 50, & 60 numbers stands for FA %age replacements by weight of cement and whereas, the 0.1, 0.15 & 0.2 stands for molasses dosage by weight of cement.

Table 3.16: Notations for different mix scenarios

Mix ID	R	M40, 0.1	M50,0.15	M60,0.2
Cement	100%	60%	50%	40%
FA	0%	40%	50%	60%
Molasses	0%	0.1%	0.15%	0.2%

3.3.9 Slump Test of Fresh Concrete

A slump test is a type of physical property test done on fresh concrete to determine the concrete's ability to be placed, transported, easy flow, and other properties. The concrete slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete. The slump cone test can be used as an indicator of an improperly mixed batch. If the concrete cannot flow because the consistency or slump is too low, there are potential problems with proper consolidation. If the concrete will not stop flowing because the slump is too high, there are potential problems with mortar loss through the formwork, excessive formwork pressure, finishing delays, and segregation. The test was done with accordance of ASTM C143 (2012) standard. To undertake this test slump cone (which has the shape of a frustum of a cone having dimensions, base diameter 200 mm, top diameter 10 mm, and height 300 mm), tamper rod (16 mm in diameter and 600 mm in length), Ruler, flat pan and tools were used in accordance to the procedures given in Appendix B7 and Pictures shown in Appendix E2.

3.3.10 Casting of Samples, Specimen Preparation and Curing

Concrete was cast in cubes size (150*150*150) mm to investigate the compressive strength of the concrete. Different mixes are prepared at different percentage replacement cement by FA and Molasses as an admixture. The concrete was mixed, placed, and compacted in three layers. Compaction for the specimens was done using a vibrating table. The applied duration of vibration depends on the slump of concrete. Vibration is applied until the concrete becomes relatively smooth and large air bubbles stop showing up on the top surface. The specimens were stored in moist air for 24 hours and the specimens were removed from the mold after 24 hours. Then submerged in clear freshwater at room temperature until the specimens are taken out from the curing tank just before the test, the concrete was surface dried for one hour in the moist condition before conducting the test. The pictures of these experimental works are shown in Appendix E3 and E4.

Three samples were cast for each percentage of replacement at 7, 28 and 56 days of curing for the compressive strength test. Due to concrete gains maximum strength at 28 days and 65 % of the target strength by the time of 7 days, those curing periods were chosen. In addition, in the special mixes in which HVFA is used to replace cement, the samples were also cast and cured for 56 days since pozzolanic materials gains maximum strength at late age than early curing ages (Gopal M., 2014). The minimum number of samples specified by ASTM C39 is three. To acquire a reliable value, three samples were prepared for each test in the current study. On other hand, (70*70*70) mm cube sized specimens were cast to carry out water absorption test. Three specimens were cast for each percentage of replacement at 28 and 56 days of the curing period. Due to the early hydration process of OPC, ASTM C140 recommends that water absorption concrete should be tested after 28 days of curing. As shown in Table 3.17, 90 and 60 specimens were casted for compressive strength and water absorption tests respectively.

Table 3.17: Number of specimens casted for compressive strength and water absorption tests

Mix ID	Number of Specimens				
	For Compressive Strength test			For Water absorption test	
	7days	28days	56days	28days	56days
R	3	3	3	3	3
M40,0.10	3	3	3	3	3
M40,0.15	3	3	3	3	3
M40,0.20	3	3	3	3	3
M50,0.10	3	3	3	3	3
M50,0.15	3	3	3	3	3
M50,0.20	3	3	3	3	3
M60,0.10	3	3	3	3	3
M60,0.15	3	3	3	3	3
M60,0.20	3	3	3	3	3
Sub total	30	30	30	30	30
Grand total		**90**		**60**	

3.3.11 Hardened Concrete Test

Systematic testing of raw materials, fresh concrete, and hardened concrete are an inseparable part of any quality control program for concrete, which helps to achieve higher efficiency of the material used and greater assurance of the performance of the concrete regarding both strength and durability. The test methods should be simple, direct, and convenient to apply.

Despite that, "In this study, the term 'Physio-Mechanical properties of concrete' encompasses a focused investigation into the unit weight, compressive strength, and durability (water absorption) of high-volume fly ash concrete incorporating molasses as an admixture. While the broader scope of 'Physio-Mechanical properties' typically includes flexural and tensile strength, it was deliberately narrowed the focus to these specific properties due to well-founded reasons. Fly ash, a pozzolanic material with lower specific gravity than cement, primarily enhances compressive strength, making it a pivotal factor in assessing concrete quality.

Molasses, on the other hand, primarily influences workability and curing but does not significantly impact flexural or tensile strength. The current study aims to delve into the underlying chemistry and long-term effects of these materials, emphasizing the critical role of compressive strength and durability in ensuring the practical applicability and quality of the blended concrete. Thus, the term 'Physio-Mechanical properties' in this context is justified by a thoughtful consideration of the materials' properties and their direct relevance to the overall concrete performance." And the theoretical foundation that supports this was also reviewed and established in section 2.2.4.2 of the report.

3.3.11.1 Compressive Strength Test

Compressive strength is the ability of hardened concrete to withstand axial loads without any cracks or deflection. Therefore, this test aims to determine the compressive strength of hardened concrete by replacing cement with a different percentage of FA and using different dosages of Molasses as an admixture after 7, 28, and 56 days of the curing period. The balance, mold, temping road, compressive test machine, trowel, shovel, and brush were used in the test. A concrete cube of sample size 150 x 150 x 150 mm were cast to investigate the compressive strength of HVFA concrete in which Molasses used as an admixture and normal concrete. The researcher determined the compressive strength after 7, 28, and 56 days of curing by using an automatic compressive strength test machine having a load capacity of 3000 KN at Adama Science and Technology University, Construction Material Laboratory, in accordance with (ASTM C39).

To undergo the compressive strength test, the cast cubes were taken out of the curing water after 7, 28, and 56 curing periods and wiped out excess water from the surface. The test machine was then cleaned, the samples were placed in the test machine turn by turn, and the load was applied at a rate of 14 N/mm^2/minute. Three cube samples for each mix IDs were examined for compressive strength at 7, 28, and 56 days of curing using. The compressive strength was computed by dividing the highest load by the cross-sectional area of the samples (Equation 3.14) and the average values were used to determine the compressive strength of concretes. When the specimens failed, the maximum load was recorded, and finally, the compressive strength was calculated automatically in accordance of equation 3.14. Some pictures showing the procedures of the test are attached in Appendix E5.

$$\text{Compressive Strength} = \frac{\text{Load}}{\text{Cross-sectional area of the sample}} \text{............Equation 3.12}$$

The test results were compared to the target mean and characteristic strengths. The target mean strength is determined by designing the concrete mix according to the code. The characteristic strength is the value of concrete strength at which no more than 5% of the test results fall below the value. The strength range between the highest and lowest individual test results was calculated and found to be below 15% of the mean. An invalid result implies that the test technique has one or more flaws. There were no incorrect results in this study. Aside from that, no more than 5% of individual test results fell below the characteristic compressive strength.

3.3.11.2 Durability Test

The ability of concrete to withstand weathering, chemical attack, water absorption, and abrasion while maintaining its desired engineering properties is called its durability. Concrete's durability can be determined in a variety of ways. According to Sathyan and Anand (2019) Report, major durability problems are associated with sulphate attack, acid attack, chloride penetration etc. The important method to improve the durability characteristics of concrete is to reduce the permeability of concrete by giving good compaction. Plasticizer addition is one of the methods to improve the workability and thereby reducing the porosity. A water absorption test was used to determine the concrete's durability for the current study. Water absorption is the measure of water penetration resistance of concrete specimens.

A concrete cube of sample size 70 x 70 x 70 mm were cast to investigate the water absorption capacity of special and normal concrete. This research examined the water absorption of normal and special concrete at curing periods of 28and 56 days to determine the water tightness of concrete. The water absorption test procedure followed was: after 28 and 56 days of curing, the samples were taken out of the curing water and dried at a temperature of 105°C for 24 hours, weighed, then immersed in curing water for 72 hours, weighed again, based on (ASTM, C1585), and the highest water absorption limit is 10%. The increase in weight as a percentage of the original weight is expressed as water absorption. Appendix E6 shows procedures followed while conducting this test. The water absorption and percent reduction can be computed based on the following formula.

$$\text{Water absorption \%} = \frac{A-B}{B} \times 100\ \% \text{..........................Equation 3.15}$$

Where, A: Weight of Saturated Surface Dry concrete, B: Weight of oven-dry concrete, C: the difference between % absorption of normal concrete and special concrete.

$$\% \text{ reduction} = \frac{C}{\% \text{ absorption of normal concrete}} \text{ X } 100 \% \text{........Equation 3.16}$$

3.3.11.3 Microstructural Test

The concrete microstructural analysis is a methods used for determining the morphological characteristics of the concrete. The study of concrete microstructure has greatly benefited from microscope examination and X-ray microanalysis. SEM and XRD techniques are developed to image the complex microstructure of concrete and provide images with sub-micrometer resolution. The SEM uses a focused beam of electrons to scan the specimen and measures any of the signals produced by the beam's interaction with the specimen. The size, shape, surface roughness, and fracture of a surface are all investigated using topography images. Quantitative spot chemical analysis and element distribution maps are provided by X-ray microanalysis (Stutzman, 2000)

After 56 days of curing, samples were taken from the control mix and 60% replacement to conduct SEM analysis of the concrete. Initially, the samples were prepared by cutting a portion from the cured specimen and reducing them to the required size. Then the prepared samples were taken to the SEM laboratory. Finally, after the analysis was conducted, the displayed morphological images of the samples were analyzed qualitatively through the observation of the images.

To perform XRD analysis on the concrete, portions of the concrete were extracted from the control, and 60% replacement specimens which were cured for 56 days. The portions were taken from the top, middle, and bottom of the specimens. The samples were then pulverized and sieved to make powder and taken to the XRD laboratory. The powdered samples were subjected to X-ray diffraction at a 2θ Angle. Following the analysis, the peaks were generated on the Origin Software using the collected XRD data in terms of intensity and degree of diffraction. Finally, the peaks were interpreted using the X'pert High Score plus software.

3.3.12 Environmental and Cost Performance Exploration

The cost and environmental effects of HVFA concrete in which molasses was used as an admixture must be evaluated for the purpose of mass production and field application. The environmental and cost implications of using HVFA as a partial cement replacement and Sugarcane molasses as an admixture in concrete were explored in terms of raw materials usage, energy usage, CO_2 emissions, and cost implications. Molasses was not considered in the environmental and cost evaluation of concrete in the current study. This is because the objective of the evaluation is basically associated with the reduction in cement consumption as a result of FA replacement wherein molasses is used as an admixture to improve some properties of concrete not to replace cement. Moreover, if the evaluation needs to be done in combined with molasses, additional control mix in which chemical admixture is used than the ordinary conventional concrete has to be employed too but it is not part of the investigation.

3.3.12.1 Assessments of Environmental Impacts

I. Raw Materials Consumption

To investigate raw material usage, raw material consumption for the production of one cubic meter of concrete with and without FA was calculated and compared. The calculation was made based on the report of a study done by Waqas et al. (2021) which revealed that 1.6 tons of raw materials are consumed for the production of one ton of cement that will result in the liberation of 1 ton of CO_2 in the atmosphere.

II. Transportation Impact (T_i)

During material transportation, there are fuel energy consumption and greenhouse gas emissions. Thus, Eq. 3.17 is applied to assess the transportation impacts (Makul 2020; Mclellan et al. 2019; Oyebisi et al. 2022).Where, Mw = material's weight (kg); dt = truck distance travelled (km); and Tc = transport factors for EE (MJ-eq/tonne-km). The transportation factors for different modes of transportation are given in table 3.18.

Table 3.18: Transportation factors (Tc) for various types of transportation

Transportation mode	Impact group			Reference
	Energy demand (MJ-eq per tonne-km)	GWP ($kgCO_2$-eq per tonne-km)	GTP ($kgCO_2$-eq per tonne-km	
Truck, road	2.275	15.9×10^{-2}	16.6×10^{-2}	(Habert et al. 2020; Makul 2020; Mclellan et al. 2019)
Freight, rail	32.5×10^{-2}	3.9×10^{-2}	-	
Transoceanic, ship	21.6×10^{-2}	16.5×10^{-2}	-	

$$Ti = \sum_{i=1}^{n} \left(\frac{Mw \times dt \times Tc}{1000} \right) \text{..............................Equation 3.17}$$

III. Embodied Energy (EE)

EE is the total energy required for the extraction, processing, manufacture and delivery of building materials to the building site. Energy consumption produces CO2, which contributes to greenhouse gas emissions, so embodied energy is considered an indicator of the overall environmental impact of building materials and systems (Venkatarama et al., 2016) Calculating the embodied energy of concrete materials is crucial for choosing the optimal choice for decreasing a structure's entire energy consumption and environmental influence. The EE is computed by summing the product of the quantity of each material (QM) with its embodied energy coefficient (EEc) (Nizam et al., 2018). The production of $1m^3$ of concrete consumes energy. Hence, Eq. (3.18) is engaged to evaluate the embodied energy of concrete constituents within the cradle-to-gate boundary (Andrew 2019; Barcelo et al. 2020; Miller et al. 2019). The EE coefficients for different materials were given in Table 3.19

$$\text{Cradle- to - gate} = (1 + m) \sum_{i=1}^{n} (Mw \times EEc) \text{ ....Equation 3.18}$$

Where, Mw = weight of material (kg); m = EE wastage factor (%), taken as 22% (Zin et al. 2021); EEc = EE factors (MJ-eq/kg)

Table 3.19: EE and GWP coefficients for concrete constituents

Constituent	EEc (MJ-eq/kg)	GWPc (kg CO2-eq/kg)	Reference
PLC	5.50	95×10^{-2}	(Andrew 2019; Barcelo et al. 2020; Mclellan et al. 2019; Zin et al. 2021)
GGBFS	1.60	8.3×10^{-3}	
CCA	1.35	8.0×10^{-3}	
FA	8.1×10^{-2}	5.1×10^{-3}	
CA	8.3×10^{-2}	5.2×10^{-3}	
SH	18×10^{-2}	86×10^{-2}	
SS	5.37×10^{-2}	78×10^{-2}	
Water	1.0×10^{-2}	1.0×10^{-3}	

IV. CO_2 Emissions

The global cement industry contributes around 2.8 billion tons of the greenhouse gas emissions annually, or about 7-8% of the total man-made greenhouse gas emissions to the earth's atmosphere (Herath et al. 2020; Vora and Dave 2013; Zin et al. 2021). Hence, the studies established that waste materials have zero embodied energy and GHG emissions except the energy consumption and emissions during transportation and further preparation of those materials. Global warming is caused by CO_2 emissions into the atmosphere. The global warming potential (GWP) examines the cumulative effect of GHG emissions. This effect comprises short- and long-term gases, altering the mean atmospheric temperature (Oyebisi et al. 2022). Thus (Eq.3.19) was used to assess the global warming impact of concrete constituents (Adesina 2020; Andrew 2019; Barcelo et al. 2020).

$$\text{Cradle- to - site} = (1 + n)\sum_{i=1}^{n}(\text{Mw x GWPc}) + \text{TiGWP} \quad \text{……………………Equation 3.19}$$

Where, Mw = weight of material (kg); n = GWP wastage factor (%), taken as 19% (Barcelo et al. 2020); GWPc = GWP factors (kgCO_2-eq/kg); TiGWP = transport impact of GWP (kgCO2-eq/m^3). The approximate values of TiGWP and GWPc were given in Tables 3.18 and 3.19 respectively.

3.3.12.2 Cost Evaluation

The cost of one cubic meter of concrete without and with 60% of FA was computed to explore cost improvement associated with reduction in cement consumption. In a study done by Eshetu (2020) on Cost Optimization of C-30 and C-40 concrete mixtures using Superplasticizers, it was reported that from the total cost of concrete work, the material takes around 70%, labor 13% and the rest 17% is equipment, overhead, and profit. The cost of cement takes 61% of the material cost and 42% of the total concreting work cost.

Hence, in the current study, only the cumulative cost of concrete constituent materials was used to compare the cost incurred by those materials per 1m^3 of the conventional concrete and the HVFA concrete provided that a rough assumption was established by the researcher that the other costs (labor cost, equipment cost, overhead, and profit) used in producing both types of concrete are equal.

The current market price of materials and the cost of FA preparation were used to calculate the concrete cost. Generally, Conventional cost analysis method (A comparative analysis of the cost between the conventional concrete and the HVFA concrete) was applied to determine the possible cost saved per cubic meter of concrete from the reduction of cement content as a result of using FA. The cost analysis was done based on current construction materials price in Addis Ababa without including loading and unloading costs. Procedurally,

1. The current price of concrete ingredients was collected from (www.2merkato.com).
2. The workability, compressive strength and water absorption were set as Performance Criteria for the selection of the optimum mix.
3. Cost analysis per cubic meter of conventional C-30 concrete was made.
4. Cost analysis per cubic meter of the optimum mix was made.
5. The difference was taken as the cost-saving made from cement content reduction
6. The cost saving per cubic meter of concrete was determined.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the study findings derived from the analysis and discussion of laboratory test results conducted on 10 different concrete mixtures having different cement content, coal Fly Ash percentage and sugarcane Molasses dosages. The chapter begins with the discussion of the blended paste consistency and setting time. Furthermore, the discussions of the concrete's workability, compressive strength, water absorption, and microstructure were included consecutively. Finally, the possible environmental and cost improvements of using HVFA as a partial replacement for cement in concrete production and Sugarcane Molasses as an admixture were investigated and presented.

4.2 Normal Consistency and Setting Time of Blended Paste

4.2.1 Normal Consistency of Blended Paste

The normal consistency of hydraulic cement is the optimum percentage of water content required to make a neat paste of satisfactory workability. From the test results, the normal consistency of the control cement (without FA and molasses) paste was 29%. This indicates that the amount of water required to make a cement paste is 29% of the weight of cement. As seen in Figure 4.1, the usual consistency of all blended pastes was less than the control paste and was in a decreasing pattern.

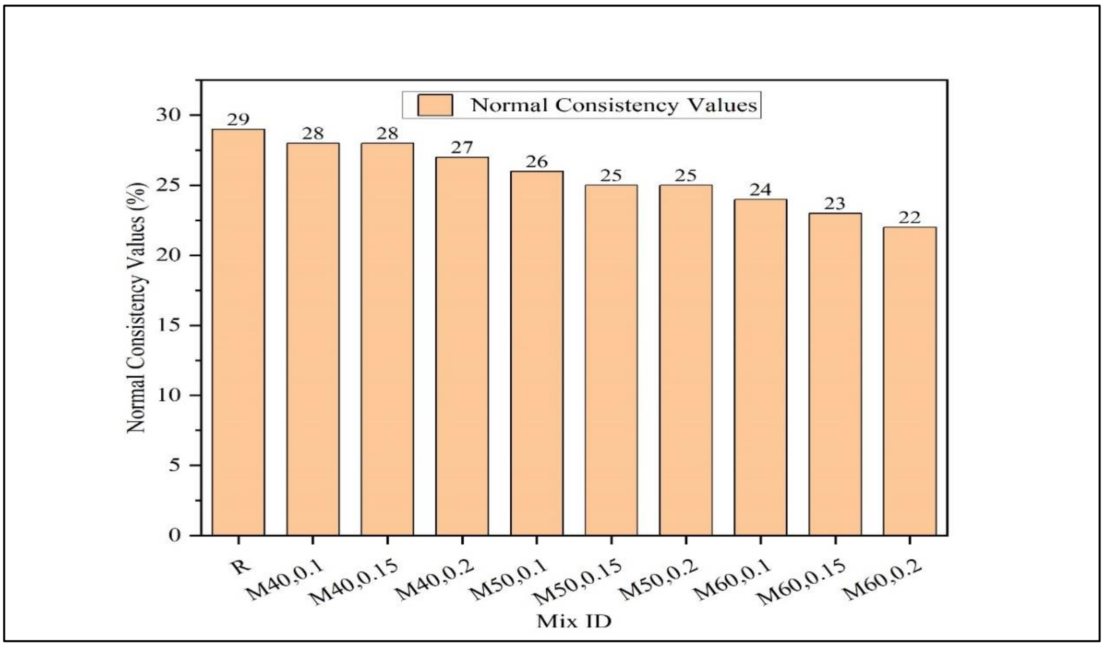

Figure 4.1: Normal consistency of blended cement paste

As indicated in Fig. 4.1, for the available mix scenarios, normal consistency of blended pastes was attained at 29, 28, 28, 27, 26, 25, 25, 24, 23, and 22%, as presented in the figure from left to right which depict that the normal consistency of all blended pastes were in ranges of ASTM C187 (2016), 22% - 30%. Based on the current investigation, the minimum consistency (22%) was recorded for 60% FA and 0.20% molasses.

As illustrated in Figure 4.1, as the FA replacement percentage and molasses dosage increased, the normal consistency of all pastes get reduced linearly. Furthermore, in each replacement groups (40, 50 and 60%), an increase in molasses dosages resulted in decreased normal consistency. This is to mean that keeping the FA replacement percentage constant (40% or 50% or 60%), as the molasses dosage increased from 0.1% to 0.2%, the water demand of the paste decreased considerably. The outcome clearly demonstrates that molasses increases the flowability of cement paste. Utilizing this effect, the amount of water in a mixture can be decreased while cement paste strength is increased. This indicates that the sugarcane molasses act as a water reducing admixture.

According to Rashid et al. (2019), molasses have large percentage of products of alkaline hydrolysis in the form of inverted sugar, which contain free carbonyl group, and ultimately lead to the plasticizing effect of cement paste. Another product in molasses, made by pyrolysis of sucrose and contain particle with molecular weight up to 13200, also contributes to the plasticizing effect. This implies, it has also been proven that adding molasses lowers the amount of water needed to get the typical consistency of cement paste and can be used in place of a plasticizer.

4.2.2 Setting Time of Blended Paste

The objective of this test was to determine the initial and final setting time of cement paste with normal consistency. The observed values of the cement pastes' initial and final setting times for varied FA percentages and molasses dosages were recorded and the graph of different blended cement pastes against their setting time result was thus plotted and presented in Figure 4.2. The cement paste without the addition of FA and molasses set up quickly; its initial and final setting times were 104 and 245 min, respectively. The initial and final setting times were prolonged by the addition of FA and molasses for all mix scenarios. The initial setting time of blended paste was retarded from the control paste by 5.8%, 7.7%, 13.5%, 21.2%, 24%, 28.9%, 37.5%, 44.2% and 58.7% at the consecutive blended pastes from left to right respectively as in Figure 4.2. While the final setting was retarded by 4.5%, 5.7%, 8.16%, 10.6%, 14.3%, 16.7%, 29.8%, 32.2% and 43.7% at the consecutive blended pastes from left to right respectively as in Figure 4.2.

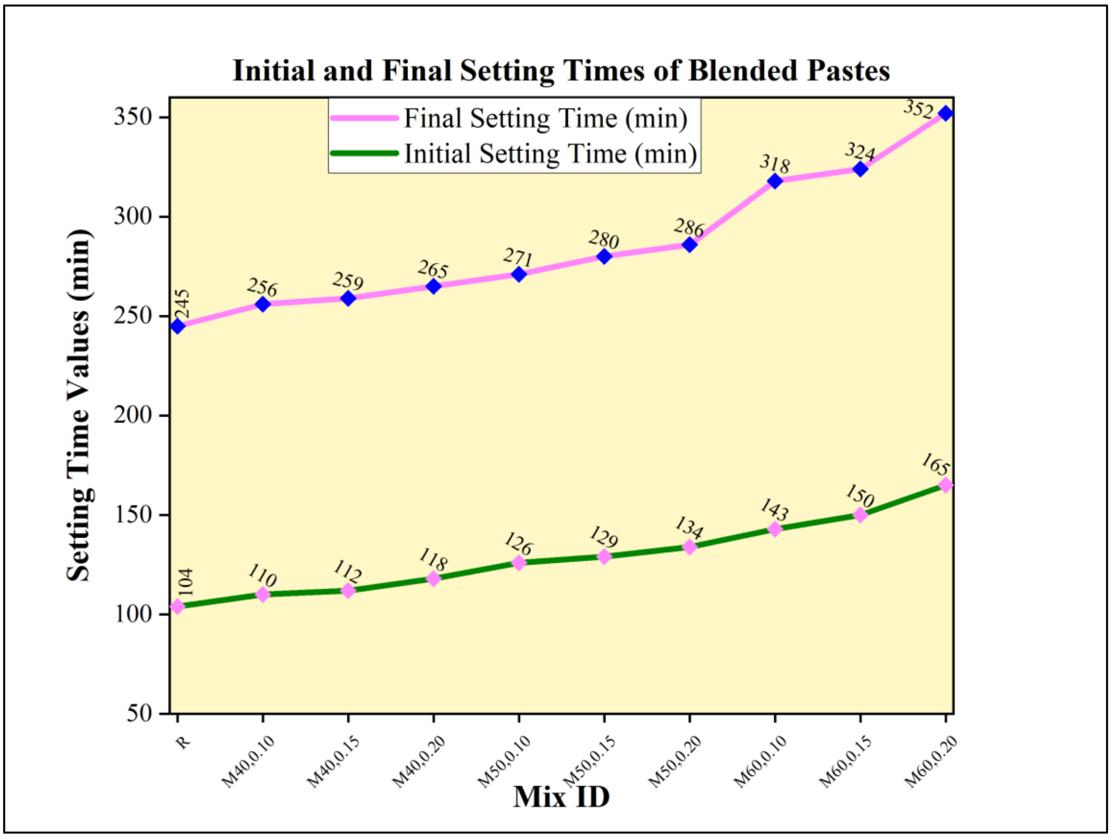

Figure 4.2: Initial and final setting time of blended paste with FA and Molasses

The result shows a linear increment in both setting times right from the first mix combination to the end. Furthermore, with respect to the control paste a 5.8% minimum retardation (at 40% FA and 0.1% molasses) and a 58.7% maximum retardation (at 60% FA and 0.2%) of initial setting time was recorded. Whereas the final setting time was retarded to a minimum of 4.5% (at 40% FA and 0.1% molasses) and to a maximum of 43.7% (at 60% FA and 0.2%). However, this retardation was within the limit as specified by ASTM C150 (2018) standard which specifies that for a vicat setting time test, the initial setting time shall not be less than 45minute and the final setting time shall not be more than 375minute. It is obvious that the initial and final setting times of FA and molasses-containing paste have increased due to FA’s delayed pozzolanic reaction and molasses' retarding property.

It was recognized that the adsorption of sugar and sugar acids on the surfaces of hydrating cement particles along with hydration products lead to retarding action and thus the possible reason for delay in the setting time is postponed hydration of the Tricalcium silicate (C_3S) by saccharides in the molasses (Rashid et al. 2019). These scholars also concluded in their findings that molasses is a by-product of sugar production; which not only improves concrete fluidity but also prevents early hardening of cement paste. The same retardation effect is expected from molasses due to its sucrose content (Yildirim and Altun 2012). Therefore, the increase in the initial and final setting time of cement paste could be as a result of retarded hydration due to the presence of 46.8% of sugar in the sugarcane molasses used. Because sugar increases the concentrations of calcium, aluminum and iron in cement paste. The sugar molecules combine with these metals to form insoluble chemical complexes that coat the cement grains.

Another reason for the extension of the setting time is HVFA concrete has low early strengths due to the slow pozzolanic reaction of fly ash at early ages. However, with time the unreacted fly ash reacts and result in latter age strength gain in HVFA concrete (Herath et al. 2020). Referring to the above results, it can be concluded that smaller dosages of the molasses (up to 0.20% by weight of cement) and HVFA are more effective in retardation of the setting times. Molasses exhibited a rather significant retarding effect when used in combination with in cement. This can make molasses to be a preferable retarding admixture and HVFA to be a best SCM particularly in hot areas and mass concrete structures where DEF is of great importance. Furthermore, this finding can simultaneously contribute to the significant reduction in early strength of HVFA concrete incorporating cane molasses.

4.3 Slump Test for Workability of Fresh Concrete

In this experimental investigation, the workability of conventional concrete and HVFA concrete incorporated with Molasses was investigated and the slump cone test was used to investigate the level of workability of the fresh concrete. The result of the mean slump value of special and conventional concrete can be illustrated in Figure 4.3 below. The least slump value was obtained at the control mix (30mm), while the highest slump value was recorded at a mix containing 60% FA and 0.2% molasses (which is 57mm). The slump values were observed to increase linearly with increase in FA percentage and molasses dosage. Nevertheless, the slump values of all mix scenarios are in the range used for mix design (20mm – 100mm). This effect can be attributed to the shape of FA (spherical), increased volume of the mix due to lower density of FA and the retarding property of molasses and the slump results indicate that molasses can be used as an admixture effectively. Detail trial slump results for each mixes were attached in Appendix C1.

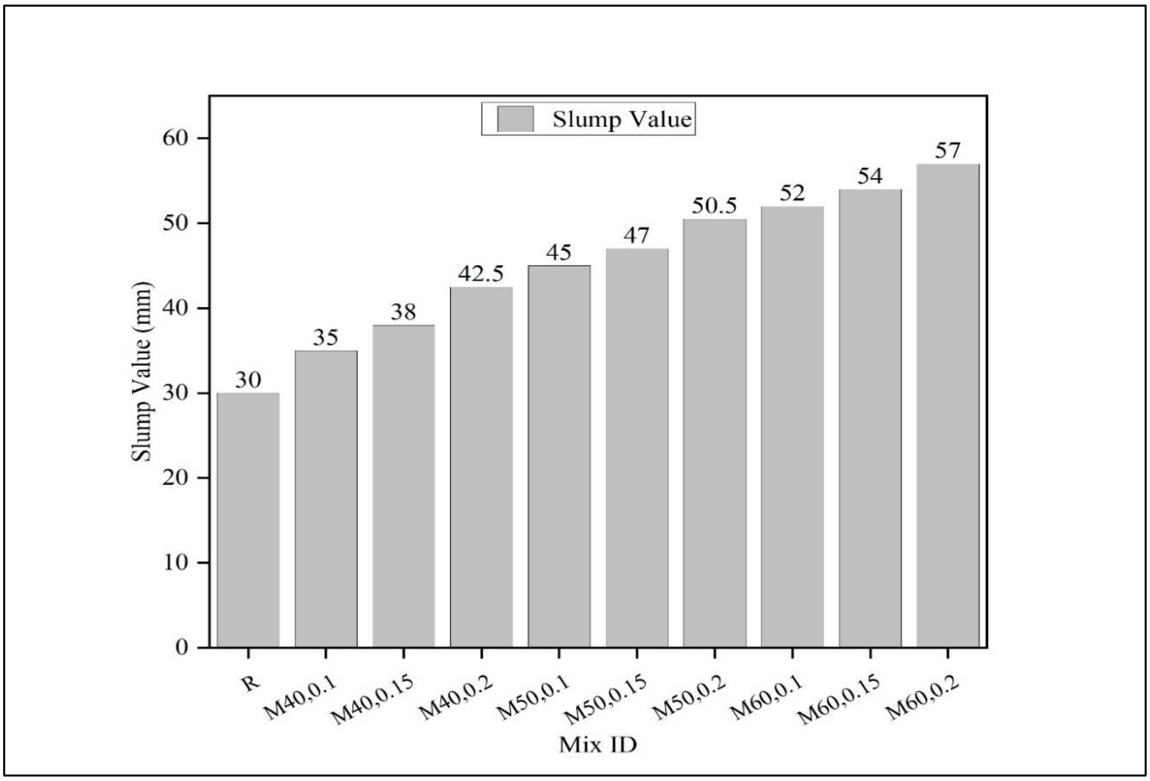

Figure 4.3: Workability of Conventional and HVFA Concrete with Molasses

As shown in Figure 4.3, the slump values of all mix scenarios increased linearly with an increase in FA percentage and molasses dosage. The influence of FA incorporation on the workability of fresh concrete was found to be inconsistent. Some studies reported an increase in the workability because of FA spherical shape, increased volume of the mix due to lower density of FA, and slower development of hydration products due to FA addition; however, some studies found a reduction in the workability of the fresh mix due to the smaller size and larger surface area of FA (Mohamed and Khallaf 2022).

In the current study, in all mixes a concrete workable than the conventional concrete was able to made among which the M60, 0.2 mix showed the best workability when compared to the other mix groups and the control mix. Hence, in this study, adding FA and Molasses to the concrete mixture improved the workability of fresh concrete and similar results were reported by (Bhide et al., 2017; Qianet al., 2021). According to the adsorption mechanism of retarder admixture, an impermeable layer will be developed on the cement particles. Due to the layer, water molecules are blocked to enter into the surface of anhydrate cement grains. As a result, slow hydration of cement occurs, which entails slowdown of the rate of strength development; in other words, the concrete mix remains plastic for certain time (Rashid et al. 2019). This effect accounts for the record of higher slump value with respect to increment in the dosage of molasses. The slump results indicate that molasses can be used as an admixture effectively. Addition of molasses to the concrete greatly influenced its workability, and this is due to the fact that molasses retardation mechanism is similar to common retarder admixture (Kassa 2019).

4.4 Hardened Concrete Test Results

Concrete that has been hardened is a robust variety of concrete that can withstand both structural and service loads. It is among the strongest and most resilient building materials. Concrete that has fully hardened is load-resistant. Based on the findings of the laboratory tests, the unit weight, compressive strength, water absorption, and microstructure of conventional and concrete blended with HVFA and molasses were examined in this section.

4.4.1 Unit Weight

The results for the average weight and volume of cube-sized (150*150*150) mm concrete specimen and the corresponding average unit weight of each mix after different curing period are presented in Figure 4.4. The highest value was obtained for the unit weight of the conventional concrete both at 28 days (2400 kg/m^3) and at 56 days (2403 kg/m^3), while the lowest value was obtained both for the unit weight of concrete with 50% FA and 0.1% molasses at 28 days (2216.3 kg/m^3) and concrete with 40% FA and 0.15% molasses at 56 days (2222.2 kg/m^3).

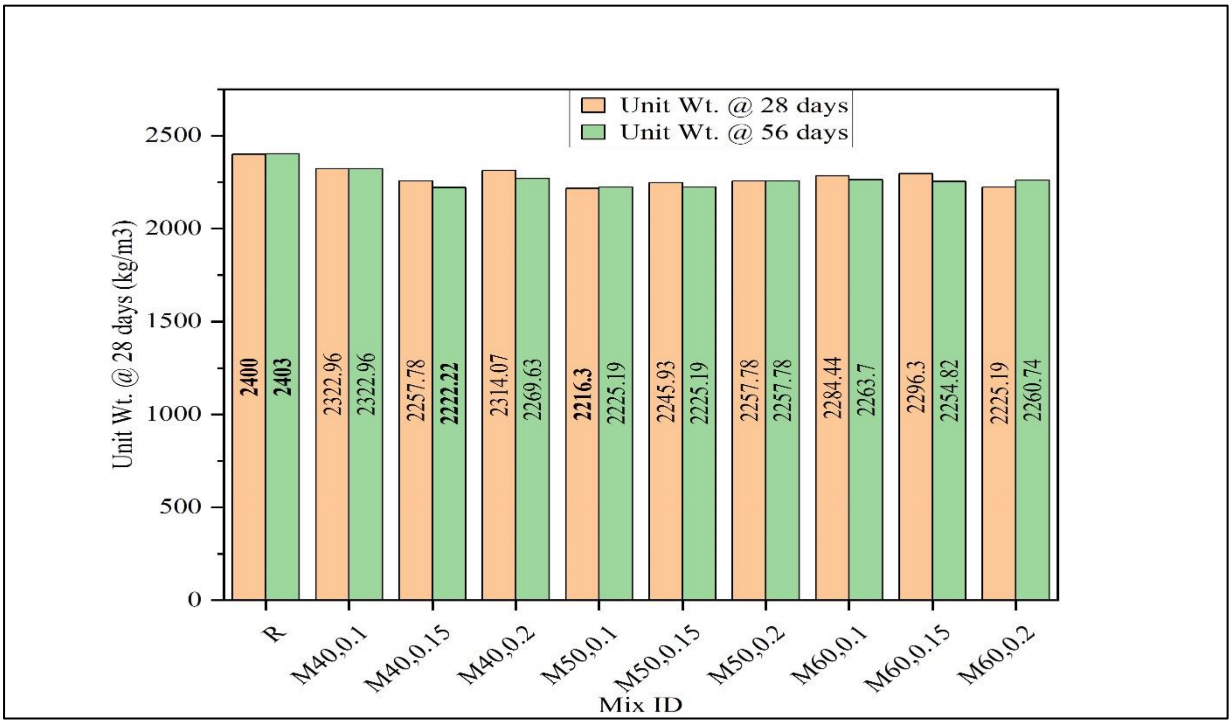

Figure 4.4: Unit weight of concrete blended with HVFA and Molasses

It can also be seen from Fig. 4.4 that the unit weight of all the mix scenarios are found to be less than the control's unit weight at both curing periods. The highest reduction in a unit weight of 7.65% was obtained when 50% of the cement was replaced by FA with 0.1% during the 28-day curing period. As illustrated in Figure 4.4, the unit weight of concrete decreases non-linearly as the percentage of replacement of FA and molasses dosage increases.

The reduction in the unit weight of concrete is due to the specific gravity of FA which was utilized in high volume. The low specific gravity of the FA, 2.1, as compared to 3.15 for that of OPC resulted in a reduction of unit weights of the blended concretes. Specific gravity of materials and their unit weight have direct relationship (Goshu, 2019).Therefore, replacing cement at specified percentage of FA is preferred for the production of lightweight concrete having good mechanical properties. The effect of molasses as an admixture on concrete durability was investigated and a unit weight increase of 1-2% occurred in all specimens. Then finally, concluded that increase in admixture did not have a significant impact on weight (Akar and Canbaz 2016).

4.4.2 Compressive Strength

Concrete's compressive strength was tested using cubes of size 150 x 150 x 150 mm that were placed under a 3000 KN compression machine and the average compressive strength results of concrete cubes with different percentage of FA and dosages of molasses are presented in Figure 4.5. The detail results of compressive strength test are presented in Appendix C2.

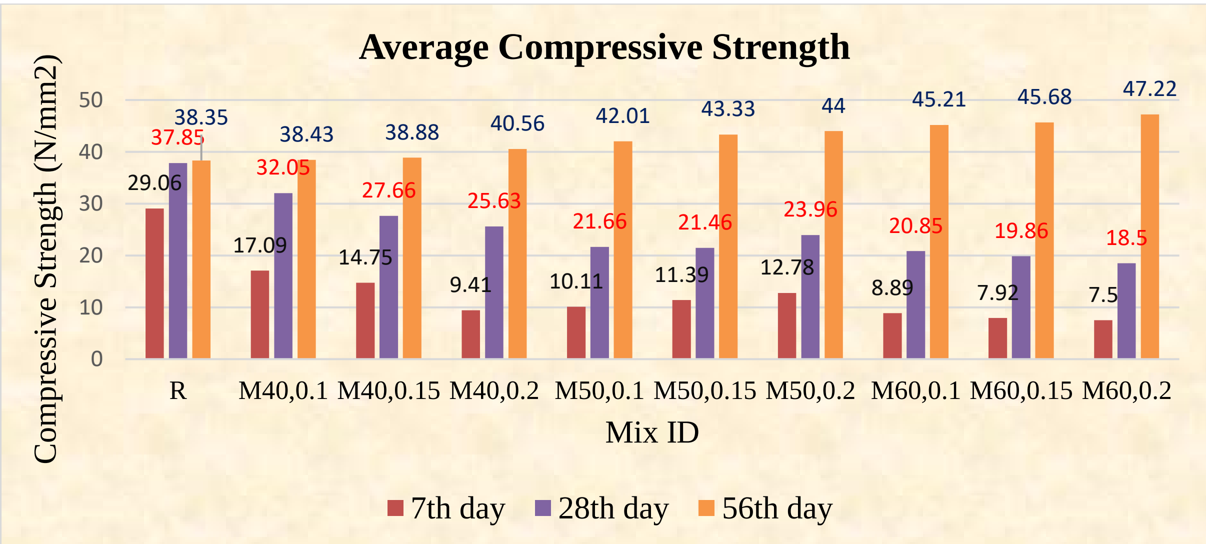

Figure 4.5: Average compressive strength of the concrete

According to the current findings, after both 7 days and 28 days curing periods, the compressive strength of all blended concrete samples was not improved as compared to normal concrete. As indicated in Figure 4.5, at 7 days and 28 days, the compressive strengths of the control mix were recorded as the highest values (29.06 N/mm^2, 37.85 N/mm^2 respectively). Furthermore, as FA replacement percentage and molasses dosage increases, compressive strength showed a linear reduction that peaks 74.2% and 51.1% at 7^{th} day and 28^{th} day respectively for the mix blended with 60% FA and 0.2% molasses concentration. This could be due to the reason that concrete with pozzolanic materials does not achieve early strength when compared to normal concrete due to slow hydration and slower setting (which is inseparable with the findings of this study which was presented in section 4.2.2). As per the review done by Herath et al. (2020) Performance of HVFA concrete incorporating additives, the pozzolanic reaction of FA primarily depends on the presence of Al_2O_3 and SiO_2 in FA, which requires portlandite to be activated. At early age, the filling effect of FA particles and their contribution towards formation of Ettringite is the primary factor in their contribution to the strength of the concrete, while as time progresses the hydration reactions are paramount.

Numerous findings have indicated that the application of FA and cane molasses in concrete impairs the early-age strength development of concrete. For instance as per Yildirim and Altun (2012) and Bhide et al. (2017) report, the concretes made with sugar addition show strength reduction at early ages, but their later age strengths might be higher. In addition, it was also reported that HVFA concrete has low early strengths due to the slow pozzolanic reaction of FA at early ages (Herath et al. 2020; Mohamed and Khallaf 2022; Rashid et al. 2019). Since most previous study findings are in agreement with the current findings, it can be concluded that not only the 7-day but also the 28-day curing period is insufficient to complete the pozzolanic reaction and gain appreciable strength.

Whereas, at the 56 days curing period, in comparison to the conventional concrete, the compressive strength of the blended concrete is significantly improved. As illustrated in Figure 4.5, at the 56 days curing period, a linear increment in compressive strength of blended concrete mixes was observed as FA content and molasses dosage increases when compared to the concrete without FA and molasses. As a result, all the concrete specimens having FA and molasses as admixture have higher compressive strength than the control specimen. Furthermore, at the 56-day, the addition of FA and molasses increases compressive strength with a range of 0.21%-23.13% (38.43N/mm^2 –47.22N/mm^2) wherein the compressive strength of the reference specimen is 38.35 N/mm^2.

Hence, in the current study, with an addition of 60% FA and 0.2% molasses, at the age of 56 days, it was able to make a concrete with a compressive strength of 1.23 (23.13% maximum increment) times that of the conventional concrete. This is necessarily be due to the pozzolanic process and the presence of retarding admixture such as sugarcane molasses in which the strength gain lasts significantly longer than with normal concrete. Similar results that can validate the current study findings were reported by different researchers. For instance, an experimental study which was done by Amran et al. (2020) to investigate the performance of high-proportion Saudi FA(SFA) (with FA content of 0%, 10%, 20%, 30%, 40%, and 50%) has been revealed that the hardened strength properties exhibited incessant and substantial enhancement at 56 days and up to one year, which is generally attributable to the pozzolanic reaction of SFA.

The presence of retarder in concrete could produce a denser C–S–H (calcium–silicate–hydrate) product in the later age of concrete (beyond 28 days) when it is compared with concrete without retarder admixture (Kassa 2019). The amorphous silica in FA reacts with the CH released by CaO hydration producing Ca_2SiO_4 hydrate to form C-S-H. As a result of this reaction, additional strength can be gained at late ages, superior strength concrete in which cement is replaced by FA partially (Du et al. 2020). FA generally enhances the strength and durability of composites over time, as it consumes the $Ca(OH)_2$ produced during the hydration of cement and makes secondary hydrates, for example, CSH (Zhao et al. 2019). It was also reported that the compressive strength of composites containing higher contents of FA was improved at a later age (56 days) compared to the controlled sample because of the slow pozzolanic reaction (Mohamed and Khallaf 2022).

Furthermore, Molasses can be used as an admixture in concrete production to reduce costs and improve compressive strength. Bhide et al. (2017) conducted experiments with different molasses concentrations (0.1%, 0.15%, 0.2%, and 0.25% by weight of cement) and found that 0.15% dosage of molasses significantly increased strength, peaking at 43.89% at 28 days. However, there was no significant strength increase beyond 28 days. In a separate study by Kassa (2019), cane molasses was tested at various dosages (0%, 0.025%, 0.075%, 0.10%, 0.15%, 0.2%, and 0.30% by weight of cement) as a concrete retarder admixture. The highest strength development was observed at 0.1% molasses dosage, with strengths of 25.4

MPa, 30.12 MPa, and 33.92 MPa recorded for 7, 14, and 28 days, respectively. This highlights the potential of molasses as a concrete admixture to enhance mechanical properties, though the optimal dosage varies.

In summary, it was made evident through current study's discussions and other researcher's findings that sugarcane molasses offers several advantages in enhancing the compressive strength of concrete through its various properties. By acting as a retarding agent, molasses effectively slows down the cement hydration process. This extended setting time enables better compaction and thorough curing of the concrete. As a result, the concrete gradually develops increased compressive strength over time. Moreover, molasses functions as a water-reducing admixture, reducing the water-to-cement ratio within the concrete mix. This reduction not only enhances workability but also decreases porosity. The combined effect of improved workability and reduced porosity contributes to a stronger concrete structure. Another key benefit of molasses lies in its ability to improve the bond between the cementitious matrix and the aggregates. This enhanced bond fosters a more robust concrete structure, which, in turn, leads to higher compressive strength as the concrete matures. In essence, sugarcane molasses acts as a multifaceted additive that, when used in concrete mixes, fosters a cohesive and interlinked series of improvements, ultimately culminating in superior compressive strength.

Having conformed with the findings and reports of other researchers, it can be concluded from the current investigation that utilization of HVFA with varying percentage (40%, 50%, and 60%) as SCMs and molasses with varying dosage (0.1%, 0.15%, and 0.2%) as an admixture in C-30 structural concrete, has not improved the compressive strength at early ages (at 7^{th} day and 28^{th} day) while the compressive strength was significantly improved at later age (56^{th} day) compared to the conventional concrete and the expected target mean strength of C-30 concrete which was computed to be 34 N/mm^2 (section 3.3.6) . This indicates, that a FA content accounting up to 60% by weight of cement and a sugarcane molasses dosing up to 0.2% by weight of cement (M60, 0.2) can be used combinedly to improve compressive strength of concrete by about 23.13%.

Justification for the Observed Compressive Strength Increment Pattern between 28days and 56 days Curing Period:

The initial reduction in compressive strength at 7 and 28 days is consistent with the slow pozzolanic reaction of fly ash at early ages, as reported by previous studies (Herath et al. 2020; Mohamed and Khallaf 2022; Rashid et al. 2019). Pozzolanic reactions involve the gradual formation of secondary hydration products, which contribute to long-term strength. However, these reactions are generally slow at early ages. At 56 days, the extended curing period allows for a more complete pozzolanic reaction to take place. This reaction continues over time, resulting in increased strength.

As the FA replacement percentage increases, the amount of pozzolanic material in the mix also increases. This implies that more reactive materials are available for the pozzolanic reaction over time. The increase in FA content may have initially contributed to the observed decrease in early-age strength due to the slow reaction. However, this effect is reversed with longer curing periods.

Molasses is known to act as a retarder in concrete, slowing down the setting and early-age strength gain. This is consistent with the findings of Altun (2012) and Bhide et al. (2017). At 7 and 28 days, the presence of molasses might have further delayed the early strength development in the blended concrete. However, at 56 days, the retarder effect of molasses may have waned, allowing the latent reactivity of the FA to fully contribute to the pozzolanic reaction. This would explain the significant strength gain observed at this stage.

The observed 56-day strength increment pattern, particularly for the 50% and 60% FA mix groups, can be attributed to the cumulative effect of both the pozzolanic reaction and the diminishing impact of the retarder. The 56-day curing period provides ample time for the full utilization of the pozzolanic potential of FA, resulting in a substantial increase in strength. The combination of increased FA content and the diminishing effect of molasses on late-age strength likely contributes to the remarkable strength gain, even exceeding the control specimen.

In summary, the observed compressive strength increment pattern at the 56-day curing period can be scientifically justified by considering the gradual development of pozzolanic reactions, the impact of increasing FA content, and the role of molasses as a retarder. This combination of factors leads to a reversal in the strength trend, ultimately resulting in significantly improved compressive strength values at 56 days. These findings highlight the importance of extended curing periods for high-volume fly ash concrete incorporating molasses as an admixture.

4.4.3 Water Absorption

A Water Absorption (WA) test was conducted to measure the durability of the concrete at 28 days and 56 days curing period and the WA and the percent reduction of WA were computed using Equation 3.15 and Equation 3.16, respectively. HVFA concrete mixtures, when properly cured, are able to provide excellent water-tightness and durability (Wang 2017). As presented in Figure 4.6, the average WAs of HVFA concrete incorporating cane molasses were 8.4%, 8.5%, 8.8%, 9.2%, 9.4%, 9.8%, 11%, 12.1% and 12.6%, for specimens containing 40%, 50%, and 60% of FA combined with varying molasses dosages of 0.1%, 0.15% and 0.2% for each FA replacement respectively after a 28-days curing period. This shows that, at 28 day, the WA of all replacements scenarios are higher than that of the control mix. Furthermore, the lowest WA occurred at the control mix (7.6%) and the highest occurred at the mix containing 60% FA and 0.2% molasses (12.6%). However, this increase in WA is still under the maximum limit set by ASTM C1585 standard (10%) except for the mixes made with 60% FA and the varying molasses dosages which have WA greater than the specified maximum value (11%, 12.1% and 12.6%). From these results, it can also be seen that, at the age of 28 days, as the FA replacement and molasses concentration increases the absorption also increases. Detailed results for all samples are presented in Appendix C3.

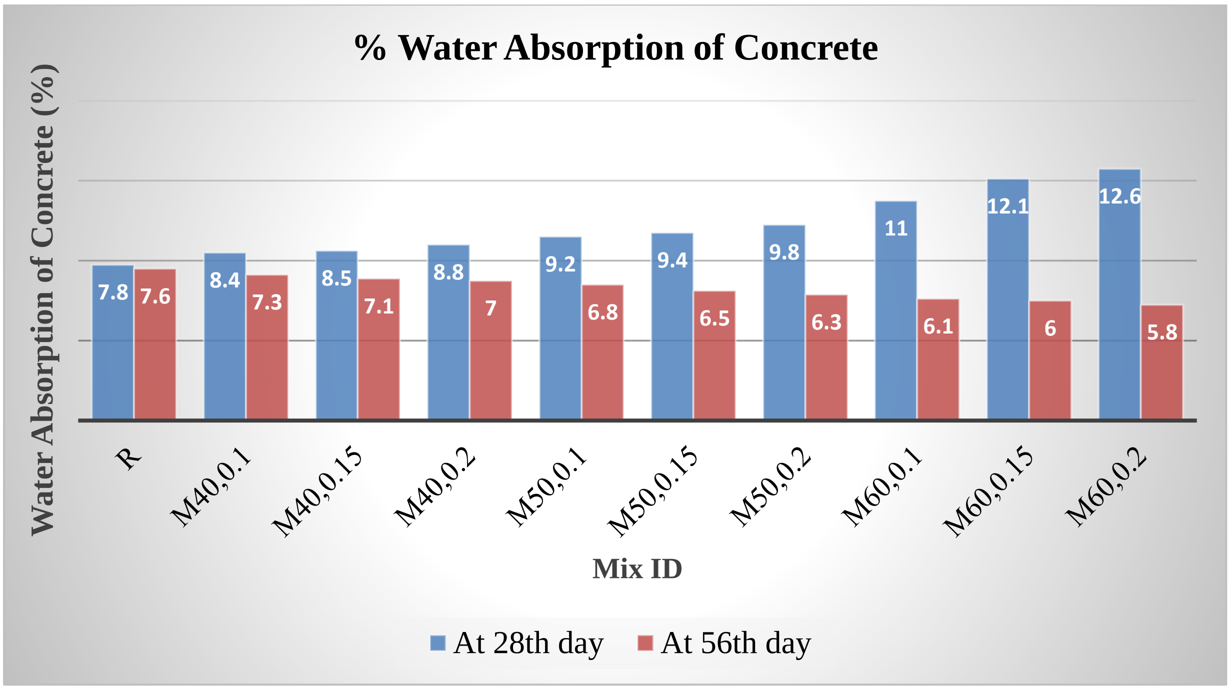

Figure 4.6: Average percentage water absorption of concrete at 28 and 56 days

This observed increment in WA corresponding to the increase in FA content and molasses dosage is attributed to the low amounts of hydration products produced at the age 28 days. Curing has a significant influence on the pore structure of the concrete, the longer the curing time, more finely the pore structure and the capillary pores are less interconnected and moreover, the porous paste/aggregate interface zone formed at early ages is densified by continuous curing in water (Dinakar et al. 2013).

In general, an increase in WA associated with an increase in FA indicates an increase in the volume of accessible pores (Khodair and Bommareddy 2017; Wongkeo et al. 2014). They have also reported that WA values increased as the amount of FA substitution increased, probably because the 28-day curing period was insufficient to complete the pozzolanic reaction.

However, WA of concrete decreased as curing ages increased from 28 days to 56 days as the result of late hydration of concrete with pozzolanic materials. As Figure 4.6 depicts, a WA values of 7.6%, 7.3%, 7.1%, 7.0%, 6.8%, 6.5%, 6.3%, 6.1%, 6.0%, and 5.8% were obtained at 56-day curing period for each respective replacement percentage placed left to right on the plot. The highest WA occurred at the control mix (7.6%) and the lowest occurred at 60% replacement with 0.2% molasses dosage (5.8%) at the age of 56 days. Despite this, at 56 days, it can be seen that the WA decreases linearly as FA content and molasses dosage increases.

Furthermore, it can also be seen in Figure 4.7 that at the age of 28 days, WA increases linearly from 7.69- 61.54% (the negative values showing no reduction in WA) whereas at the age of 56 days, WA decreases linearly from 3.95-23.68%(the positive values showing significant reduction in WA). Consequently, at 56 days, compared to conventional concrete, the highest reduction in WA is 23.68% which was obtained at a mix containing 60% FA and 0.2% molasses. These observations are consistent with the increased compressive strength of all FA and molasses blended mixes at the age of 56 days, as discussed in the previous section. Mostly siliceous fly ashes, which show pozzolanic properties, are used as cement constituents leading to better workability and positive long-term strength of concrete as well as good durability characteristics due to a denser concrete structure (Schneider 2019). Water absorption and sorptivity coefficient of both NAC and RAC are significantly reduced at 0.1% and 0.5% molasses. Reduction in water permeability with 0.1% and 0.5% molasses is ascribed to improvement in workability of concrete leading to a denser concrete at the given water/cement ratio and compaction effort (Ali and Ali 2019).

From the current study finding thus, the concrete mix with 60% FA content and 0.2% molasses at which the highest reduction in WA is recorded at 56 days curing period can be taken as the optimum mix in terms of WA of the concrete.

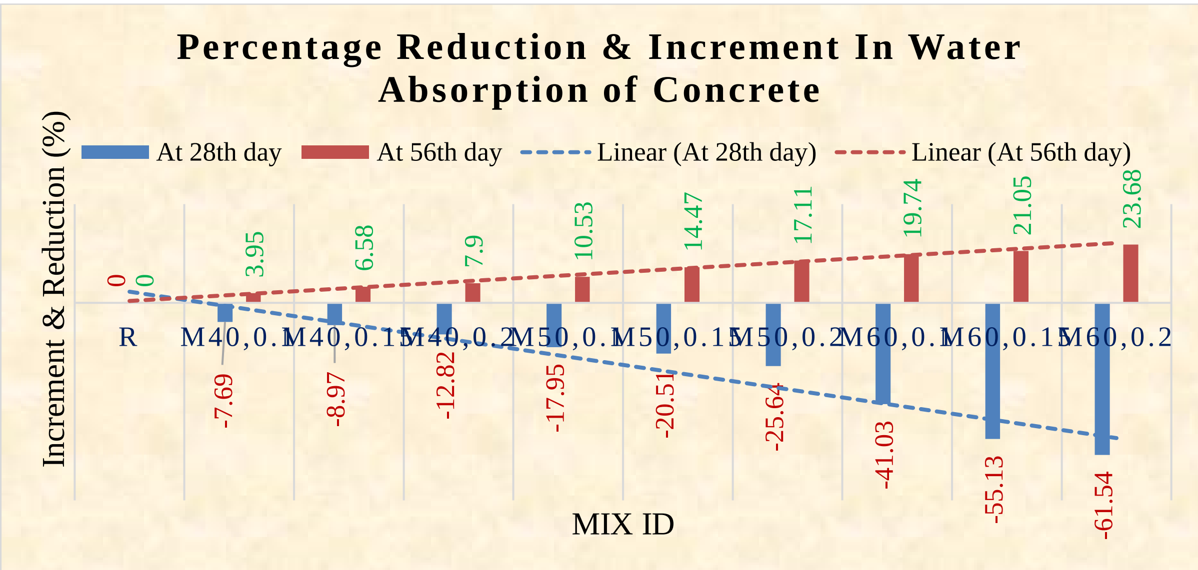

Figure 4.7: % age Increment & Reduction in WA of Concrete of all the Mix scenarios

4.4.4 Microstructure of Concrete

4.4.4.1 Scanning Electron Microscopy (SEM) Analysis

Microstructural observation of mixes of conventional concrete (R) and HVFA concrete with 60% FA and 0.2% cane molasses (M60, 0.2) through SEM analysis can be seen in Figure 4.8. R and (M60, 0.2) mixes were investigated using SEM due to the better physio-mechanical properties obtained at this mixes. SEM images are taken after a prolonged curing period of 56 days. Each mix was explored under 1500 magnification to investigate the microstructure of the concrete. Cement hydration products such as C-S-H gel, CH and ettringite are overlapped together, and they can be observed in the fracture surface micrographs. Besides, it can be obviously found that the FA and cane molasses affect the mortar microstructure. About 2µm pores are observed in the control.

One can clearly see that the hydrated products have grown together and filled some pores. It is seemed that these size pores are lessened in the mortar with 60% FA and 0.2% molasses. The pore is difficult to find, and the hardened cement pastes with 60% FA and 0.2% cane molasses show the denser microstructures. Also, a good interface and adequate compactness were evident due to the chemical reactions between the hydrating agent (calcium-silicate-hydrate) and aggregate quartz, producing a hardened network (Oyebisi et al. 2022). As indicated in Fig 4.8, the internal microstructures showed amorphous structures in spherical flakes with traces of sharp needles.

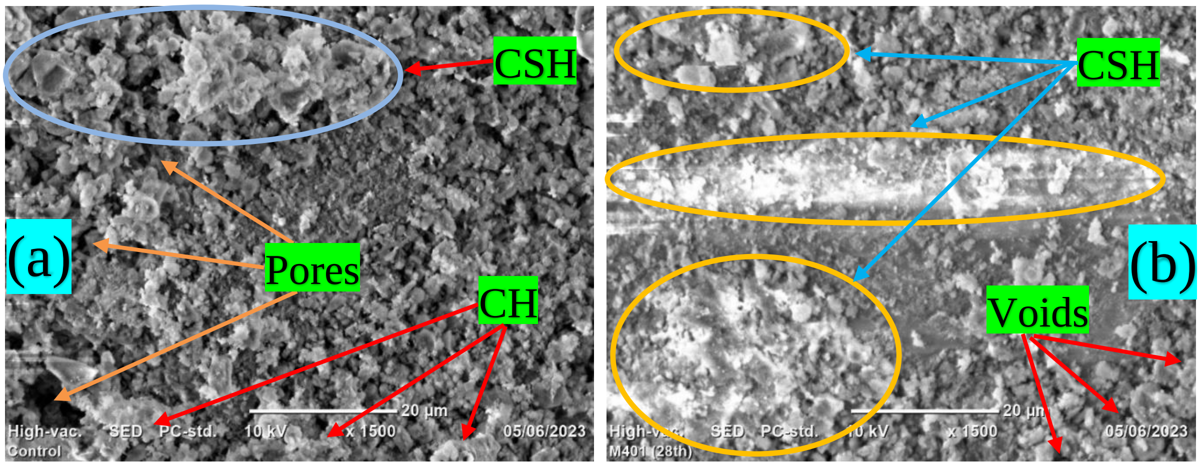

Figure 4.8: SEM images of conventional concrete (a), and HVFA concrete (b)

It is generally thought that the dark parts should be voids and cracks, whereas the grey to dark grey parts are assigned to unhydrated FA particles, CH, C–S–H, and other hydration products, and the brightest parts correspond to unhydrated cement particles. CH is identified by its relative brightness and hexagonal habits in the concrete (Du et al. 2020). In the control mix, a narrow and bright structure with crystalline formation was observed that could be CH, as shown in the Figure 4.8(a). While FA's pore structure is becoming more refined, it is still dense at 60% replacement, as shown in Figure 4.8 (b). The mix with 60% FA and 0.2% molasses could be seen, as could reduce voids on the surface due to improved hydration and a high occurrence of C-S-H gels on the surface, as short noted by the networked fiber structure. This could account for the highest compressive strength achieved at this mixed level. The formation of amorphous C-S-H gel is primarily due to secondary hydration caused by FA's pozzolanic properties (Ban et al. 2019)

In any case, the improved microstructure by addition of HVFA and molasses results in the better strength development and long-term durability, and it will consequently accelerate the actual application of concrete blended with high volume of FA and suitable content of natural admixtures such as sugarcane molasses.

4.4.4.2 X-ray Diffraction (XRD) Analysis

XRD analysis was done both on conventional concrete (R) and HVFA concrete with 60% FA and 0.2% cane molasses (M60, 0.2). Figure 4.9 (a) gives a XRD spectra of a HVFA-60

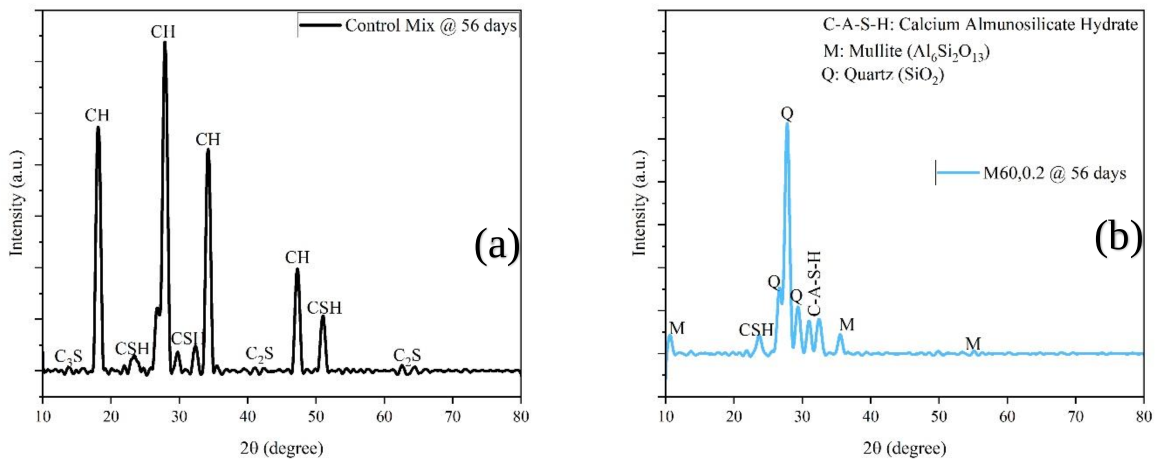

Figure 4.9: XRD Pattern a) conventional concrete, b) HVFA concrete

The spectra shows the hydration product formation. Major peaks such as portlandite (CH), C_3S, and C_2S are prevalent in conventional and major peaks, such as quartz and mullite, are prevalent in the concrete blended with HVFA (60%) and molasses (0.2%). The peaks indicate the presence of different compounds and their positions correspond to the 2θ angles. The control concrete shows peaks at 2θ = 18.24°, 27.98°, 34.3°, 47.3°, 51°, and 62.32°, which are attributed to calcium hydrate (C-H), the main binding phase in hydrated cement (Amran et al. 2020; Du et al. 2020; Herath et al. 2020). However, some new peaks are also observed at 2θ = 26.6°, 28.1°, 31.8°, and 46.7°, These peaks correspond to calcium aluminate hydrate (C-A-H), calcium carbonate (CaCO3), ettringite, and calcium hydroxide (Ca(OH)2), respectively (Alterary and Marei 2021). These peaks indicate that the SCMs have reacted with the cement and water to form additional hydration products that can improve the strength and durability of the concrete.

The pozzolanic reaction of FA primarily depends on the presence of Al_2O_3 and SiO_2 in FA, which requires portlandite to be activated (Cao et al. 2019). XRD study reveals that FA possesses both crystalline and amorphous phases. The dominant crystalline phases are quartz, mullite, kaolinite, lime and siderite with trace amounts of magnetite and hematite (Kim et al. 2020; Tydlitát et al. 2018). The amorphous glass phase is responsible for its properties (Gołaszewski et al. 2020). As reported by Kim et al. (2019), quartz and mullite are the major crystalline phases in low-calcium FA.

In addition, the M60, 0.2 mixture exhibited a higher intensity of mullite peaks than OPC mixture, suggesting the formation of C–A–S–H due to the alumina content in FA. It was reported that the supply of Al from FA can be used to generate C–A–S–H gel around the FA particles (Amran et al. 2020). Hence, presence of various hydrated products at this particular age are consistent with the results of the mechanical strength.

4.5 Environmental and Cost Evaluation of HVFA Concrete

From the previous discussions, it was noted that considering the parameters of workability, compressive strength, and water absorption, it can be concluded that a mix with 60% FA and 0.2% molasses dosage (M60, 0.2) is the optimum mix. Following this, the environmental and cost evaluation was made for the C-30 HVFAC with the emphasis given to the 60% replacement and conventional concrete.

4.5.1 Environmental Evaluation of HVFA Concrete

The environmental efficiency was evaluated in terms of raw materials usage, CO_2 emissions and embodied energy consumption for $1m^3$ of concrete.

4.5.1.1 Raw Materials Consumption

According to a study, 1.6 tons of raw materials are consumed for the production of one ton of cement that will result in the liberation of 1 ton of CO_2 in the atmosphere (Waqas et al.

2021). Those raw materials are non-renewable, which causes natural resource degradation. However, using FA, which is waste, and recycled material as a partial cement replacement in concrete production has a high contribution to saving raw material requirements for the manufacture of cement.

As tabulated in Table 4.1, the usage of FA as a cement replacement saves the use of raw materials for the production of concrete. For instance, the 40%, 50%, and 60% replacement saved about 11.1 %, 13.87%, and 16.64% of raw materials required to produce one cubic meter of concrete respectively. This is directly related to the minimization of raw materials requirements for cement manufacturing. Raw materials used to produce 425.29 kg of cement are reduced from the control by 272.2, 340.23, and 408.28 kg at 40, 50, and 60 % of replacement respectively. Therefore, compared to the conventional concrete, at the so identified optimum mix (at 60% replacement), at which 60% of cement is replaced with FA, about 16.64% (408.28 kg) of raw materials can be saved per one cubic meter of concrete production.

Table 4.1: Raw material used for one cubic meter of concrete and amount of raw materials saved

Mix ID	R (M0)	M40	M50	M60
Raw material of OPC (Kg/m^3)	680.47	408.27	340.24	272.19
Fine Aggregate (Kg/m^3)	772.62	772.62	772.62	772.62
Coarse Aggregate (Kg/m^3)	1000.23	1000.23	1000.23	1000.23
Total of virgin materials (Kg/m^3)	2453.32	2181.12	2113.09	2045.04
Fly Ash (Kg/m^3)	0	170.12	212.65	255.17
Raw materials saving for the production of 425.29 Kg of cement (Kg)	0	272.2	340.23	408.28
Saving in 1m^3 of concrete (%)	**0**	**11.1**	**13.87**	**16.64**

4.5.1.2 Embodied Energy

Energy in transportation of concrete materials:

Transportation of materials is a major factor in the cost and energy of a building. Bulk of the concrete materials in urban and semi-urban centers are transported using trucks in Ethiopia. The transportation distance may vary depending upon the location of construction materials. Table 4.2 below shows the material’s distance from the source to the place where experiment is conducted (ASTU) with their respective source location used for this study.

Table 4.2: Material's Transport Distance

Material	Source	Distance (km)
Natural river sand	Metehara	102
Coarse aggregate	Kurfa (crushing site) Adama	7
Cement	National cement factory (Dire Dawa)	326
Coal fly ash	Alemgena (A.A)	97.9

As shown in Table 4.3, the Transportation energy of materials per cubic meter of C-30 conventional concrete was computed using equation 3.17 and table 3.17.

Table 4.3: Transportation energy of materials of C-30 conventional concrete

Material	Mw (kg/m^3)	dt (km)	Tc (MJ-eq per tonne-km)	Ti (MJ-eq/m^3)
Fine Aggregate	772.62	102	2.275	179.29
Coarse Aggregate	1000.23	7	2.275	15.93
Cement	425.29	326	2.275	315.42
Transport impact (Total Energy)				**510.64**

As indicated in Table 4.4, Equation 3.18 and Table 3.18 were used to compute the EE of concrete constituents utilized to produce 1m^3 of C-30 conventional concrete.

Table 4.4: Total Embodied Energy of materials used to produce C-30 conventional concrete

Material	m [Bajpai et al.; 2020]	Mw (kg/m^3)	EEc (MJ-eq/kg) [Table 3.18]	EE (MJ-eq/m^3) [Equation 3.18]
Fine Aggregate	0.22	772.62	0.081	76.35
Coarse Aggregate	0.22	1000.23	0.083	101.28
Cement	0.22	425.29	5.50	2853.70
Total EE				**3031.33**
Grand Total EE of the conventional concrete (510.64 + 3031.33)				**3541.97**

According to the results in Table 4.3 and 4.4, the EE of cement is the highest, accounting for 3169.12 MJ. That is, cement alone is responsible for 89.5% of EE. As a result, reducing the cement content has a significant role in lowering the EE of concrete.

Table 4.5: Transportation energy of materials for C-30 HVFA concrete

Material	Mw (kg/m^3)	dt (km)	Tc (MJ-eq per tonne-km)	Ti (MJ-eq/m^3)
Fine Aggregate	772.62	102	2.275	179.29
Coarse Aggregate	1000.23	7	2.275	15.93
Cement (40%)	170.12	326	2.275	126.17
Fly Ash (60%)	255.17	97.9	2.275	56.83
Transport impact (Total Energy)				**378.22**

As stated by Mclellan et al. (2019),, waste products (i.e. fly ash and silica fume) are not allocated any of the emissions from the processes that produce them as a waste stream. The justification for this approach is that these wastes would not be generated without the production of their associated commercial product and hence the emissions should be allocated to their respective commercial products. Hence, in this study, only the possible energy consumption and emissions during transportation of FA and its further preparation (pulverization) for the concrete production was considered. The energy consumed during grinding and pulverization of FA by the ball mill machine is 0.25kWh/kg (0.9MJ/kg). Accordingly, the EE of HVFA contributed from its transportation and pulverization was computed and presented in Table 4.6.

Table 4.6: Embodied Energy of one cubic meter of HVFA concrete

Material	m [Bajpai et al.; 2020]	Mw (kg/m^3)	EEc (MJ-eq/kg) [Table 3.18]	EE (MJ-eq/m^3) [Equation 3.18]
Fine Aggregate	0.22	772.62	0.081	76.35
Coarse Aggregate	0.22	1000.23	0.083	101.28
Cement (40%)	0.22	170.12	5.50	1141.51
Fly Ash (60%)	0.22	255.17	0.90	280.18
Total EE				**1599.32**
Grand Total EE of the conventional concrete (378.22 + 1599.32)				**1977.54**

Table 4.4 and 4.6 show the concretes' EE, and the results indicated that the conventional C-30 concrete exhibited higher EE than the HVFA concrete. The HVFA concrete generated about 1977.54 MJ-eq/m3 of EE compared with PCC, which yielded 3541.97 MJ-eq/m3 of EE. This implies, to produce 1m^3 of PCC 3541.97 MJ-eq/m3 of energy is required whereas only 1977.54 MJ-eq/m3 of energy is required for the production of the same volume of

HVFA concrete. Therefore, in replacing the cement in concrete with 60% of FA, the EE energy get reduced by about 44.2% (from 3541.97 MJ-eq/m3 to 1977.54 MJ-eq/m3). The reason could be attributed to the significant reduction in cement content which is the most energy-intensive material.

4.5.1.3 Carbon Dioxide Emission

Global warming is caused by CO_2 emissions into the atmosphere. The global warming potential (GWP) that can examine the cumulative effect of GHG emissions was computed using Eq. (3.19). The equation with the reference of Tables 3.17 and 3.18 for the use of the respective emissions coefficients were used to assess the global warming impact of concrete constituents of both conventional concrete and the HVFA concrete. The approximate transport impact of GWP (TiGWP) for materials transported using truck is given to be 15.9 x 10^{-2}. The CO_2 emissions of materials of C-30 conventional concrete is presented in Table 4.7.

Table 4.7: CO_2 emissions of materials of C-30 conventional concrete

Material	n	Mw (kg/m^3)	GWPc (kgCO_2-eq/kg)	TiGWP (kgCO_2-eq/m^3)	ECO_2 (kg)
Cement	0.19	425.29	0.95	0.159	480.90
Fine Aggregate	0.19	772.62	0.0051	0.159	4.85
Coarse Aggregate	0.19	1000.23	0.0052	0.159	6.35
Total CO_2 Emission (ECO_2)					**492.1**

It is evident from table 4.7 that the total CO_2 emissions of C-30 conventional concrete is 492.1kg/m^3 out of which 480.9kg/m^3 (97.72%) is contributed by cement. Hence, it can easily be understood that an attempt made to reduce cement content can significantly reduce the ECO_2 which is revealed in table 4.8. As a result, in the concrete that utilized 40% cement and 60% FA, the cement's CO_2 emissions reduced from 480.9kg/m^3 to 192.48kg/m^3 (59.98%). The CO_2 emissions of materials of C-30 HVFA concrete is presented in Table 4.8.

Table 4.8: CO_2 emissions of materials of C-30 HVFA concrete

Material	n	Mw (kg/m^3)	GWPc (kgCO_2-eq/kg)	TiGWP (kgCO_2-eq/m^3)	ECO_2 (kg)
Cement (40%)	0.19	170.12	0.95	0.159	192.48
Fine Aggregate	0.19	772.62	0.0051	0.159	4.85
Coarse Aggregate	0.19	1000.23	0.0052	0.159	6.35
Coal Fly Ash (60%)	0.19	255.17	0.00	0.159	0.159

Total CO_2 Emission (ECO_2)	**203.84**

As indicated in table 4.8, the total CO_2 emissions of C-30 HVFA concrete is 203.84kg/m^3. Hence, the utilization of 60% FA as a partial replacement of cement made possible the reduction of CO_2 emissions from 492.1kg/m^3 for the conventional C-30 concrete to 203.84kg/m^3 for HVFA concrete (58.58% reduction in ECO_2). This is mainly because of the significant reduction in cement content from 425.29 kg/m^3 to 170.12 kg/m^3.

Therefore, in the current study, in a mix containing 60% FA and 40% cement, it was able to reduce the raw material consumption, Embodied Energy, and CO_2 Emissions by 16.64%, 44.20%, and 58.58% respectively. Replacing PC with about 25–50 wt% of SCMs reduces CO_2 emissions, energy, and cost by about 13–22%, 20–67%, and 33–80%, respectively (Oyebisi et al. 2022). Therefore, in the present circumstances, the HVFA concrete can provide a sustainable solution which can minimize the production of cement there by the usage of virgin materials, EE, and CO_2 emission can be minimized and increase the utilization of FA in the CI. Hence, HVFA concrete has a great potential for utilization in CI as it is environmentally friendly.

4.5.2 Evaluation of the Cost of HVFA Concrete

The cost of one cubic meter of concrete without and with 60% of FA (the optimum mix) was computed to explore cost improvement associated with reduction in cement consumption. The calculation of costs is based on the current market price of materials surveyed on June 3, 2023 which are presented in Table 4.9.

Table 4.9: Price of concrete ingredients in Addis Ababa on June 2023

Constituents	Unit	Rate (Birr)/unit
Cement (OPC)	Qt.	1900 ($34.84)
Sand	m^3	2300 ($42.17)
Gravel 02	m^3	2600 ($47.67)
Water	m^3	6.2 ($0.11)

According to the current market prices of construction materials, one quantal of OPC National cement costs approximately 1,900 ETB. It is about 19 ETB per kg when converted. Fine aggregate costs 2,300 ETB per cubic meter, whereas coarse aggregate costs 2,600 ETB. Furthermore, the average cost of water per cubic meter is 6.2 ETB. The estimated total cost of materials for producing one cubic meter of concrete without FA (conventional concrete) is 10,909.63 ETB ($200.03), as presented in Table 4.10 below.

Table 4.10: Estimated total cost of materials for production of one cubic meter concrete

Material	Unit	Quantity	Rate	Amount (ETB)	%age
Cement	kg	425.29	19	8080.51 ($148.12)	74.07
Sand	m^3	0.54	2300	1242 ($22.77)	11.38
Coarse aggregate	m^3	0.61	2600	1586 ($29.08)	14.54
Water	m^3	0.18	6.2	1.12 ($0.021)	0.01
Total				**10909.63 ($200.03)**	100

As calculated in table 4.10 and shown in Figure 4.10, the percentage of the estimated cost of cement, fine aggregate, coarse aggregate, and water are 74.07%, 11.38%, 14.54%, and 0.01% respectively. This indicates that among the cost of materials making 1m^3 of concrete, cement cost is much greater than the others' which accounts about 74.04% of the total material cost. Therefore it is evident from this that reducing cement content in concrete by about 60% can significantly improve the cost of concrete production.

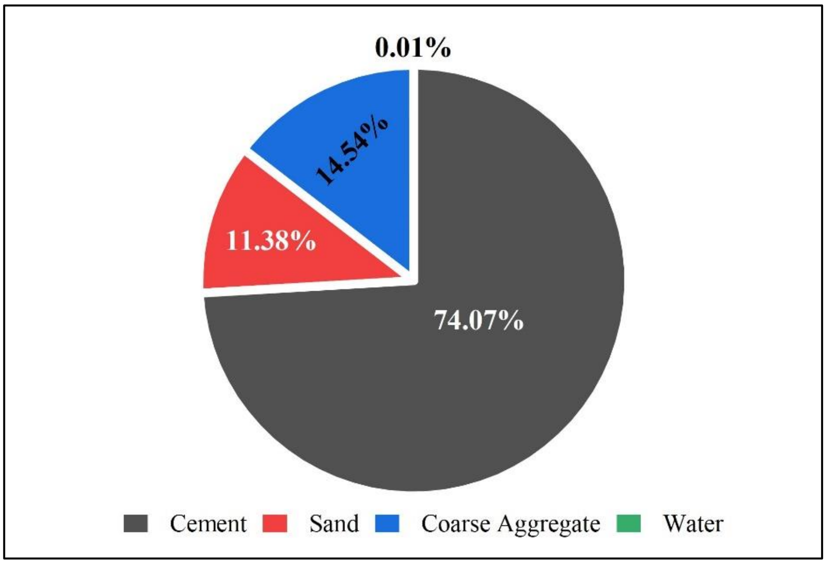

Figure 4.10: Percentage of the cost of C-30 conventional concrete ingredients

Even if the coal FA is a waste material available abundantly and collected for free, the cost incurred to transport the material from source to laboratory and the cost incurred during FA preparation (FA grinding by the ball mill machine) were computed and incorporated in the cost evaluation. As mentioned earlier, the capacity of the ball machine used for grinding of the FA is labeled to be 0.25kWh/kg. The average electric energy tariff in Ethiopia is set to be 2.58ETB/kWh or $0.05/kWh (www.ethiopianelectricutility.gov.et & www.globalpetrolprices.com). Therefore the rate of the production of pulverized FA is 0.645ETB ($0.012) per kg (0.25kWh/kg * 2.58ETB/kWh) of FA. Furthermore, the average material hauling rate in Ethiopia is 42ETB/Quintal/100km (publication.eiar.gov.et) which is after a slight conversion equivalent to 0.42ETB/kg/100km or 0.0042ETB/kg/km. Hence, since the FA hauling distance is provided to be 97.9km, the unit haulage per kg of FA is 0.41ETB/kg. Following that, the estimated total cost of materials for production of 1m^3 of HVFA concrete with 40% cement and 60% FA is given in Table 4.11.

Table 4.11: the estimated total cost of materials for production of 1m^3 of HVFA concrete

Material	Unit	Quantity	Rate	Amount (ETB)	%age
Cement (40%)	kg	170.12	19	3232.28 ($59.26)	51.06
Sand	m^3	0.54	2300	1242 ($22.77)	19.62
Coarse aggregate	m^3	0.61	2600	1586 (29.08)	25.05
Water	m^3	0.18	6.2	1.12 ($0.021)	0.02
FA (haulage)	Kg	255.17	0.41	269.2 ($4.94)	4.25
FA (Preparation)	kg	255.17	0.645		
Total				**6330.6 ($116.07)**	100

As indicated in Table 4.11, the estimated total cost of materials for production of 1m^3 of HVFA concrete is 6330.6ETB ($116.07). Moreover, as shown in table 4.11 and Figure 4.11, the percentage of the estimated cost of cement, fine aggregate, coarse aggregate, water, and FA utilized for producing 1m^3 HVFA concrete are 51.06%, 19.62%, 25.05%, 0.02% and 4.25% respectively.

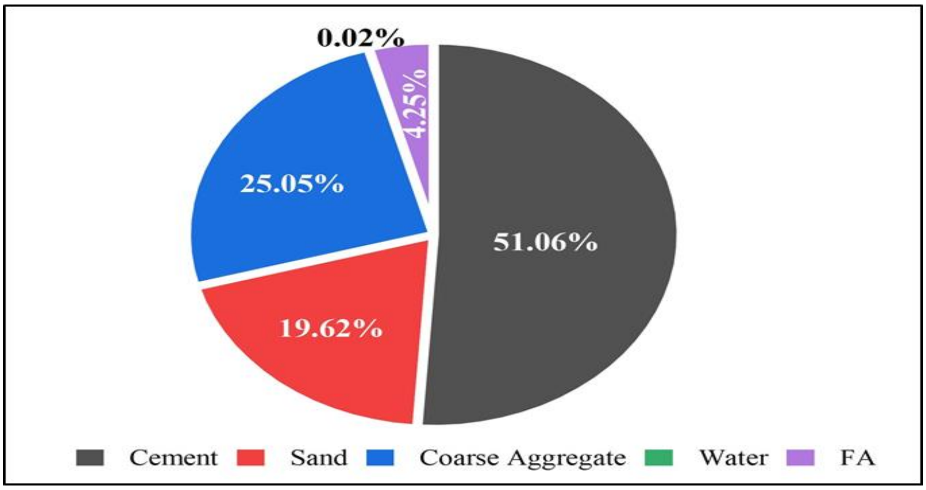

Figure 4.11: Percentage of the cost of C-30 HVFA concrete ingredients

In general, in reducing the cement content of concrete by 60% as a result of FA replacement, the cement cost reduced from 8080.51 ETB/m^3 to 3232.28 ETB/m^3 (about 60% reduction).Consequently, the estimated total cost of materials for production of 1m^3 of concrete also reduced from 10909.63 ETB/m^3 to 6330.6 ETB/m^3. Hence, it is evident from this conventional cost analysis results that by replacing cement in C-30 concrete by 60% FA, it was able to save 4579.03 ETB/m^3 (41.97%) with respect to the total cost of concrete making material. As a result of this, it can be concluded that the C-30 HVFA concrete with 60% FA is cost efficient in addition to its good environmental performance and excellent physio-mechanical and microstructural property.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of this experimental study was to investigate the physio-mechanical and microstructural properties of HVFA concrete incorporating sugarcane molasses as an admixture thereby to assess the relative cost and environmental benefit. Fresh and hardened properties of concrete, prepared with adding FA at different proportions (40%, 50%, and 60%) in combination with different dosages of molasses (0.1%, 0.15%, and 0.2% by weight of cement), up to the curing age of 56 days were investigated. In light of the laboratory results and the subsequent discussion, it can be concluded that the following deductions can be made.

- From the complete silica analysis result, the chemical composition of FA can be classified as class F pozzolana as specified by ASTM (SiO_2 + Al_2O_3 + Fe_2O_3 is greater than 70%).
- With the addition of FA and molasses, the normal consistency of the mix get reduced. Adding more FA and Molasses to the paste resulted in a lower normal consistency, which required less water and caused retardation of the setting.
- The test results indicated that a fresh concrete mix containing HVFA and Cane Molasses is more workable than the conventional concrete.
- The compressive strength test results of concrete with all mix scenario showed significant reduction at 7-day and 28-day age against conventional concrete. Whereas, at the 56 days curing period, in comparison to the conventional concrete, the compressive strength of the blended concrete is significantly improved. As a result, at this age, with an addition of 60% FA and 0.2% molasses, it was able to make a concrete with a compressive strength of 1.23 (23.13% maximum increment) times that of the conventional concrete.
- At the age of 28 days, as the FA replacement and molasses concentration increases, a linear increase in WA was observed (from 7.8% at the control mix to 12.6% at a mix containing 60% FA and 0.2% molasses). However, WA of concrete linearly decreased as curing ages increased from 28 to 56 days (from 7.6% to 5.8%). Consequently, at 56 days, compared to conventional concrete, the highest reduction in WA is 23.68% which was obtained at a mix containing 60% FA and 0.2% molasses.
- The microstructure of the concrete with 60% of FA and 0.2% molasses on day 56

shows the formation of additional C-S-H gel in the concrete due to the higher silica content of the ash.

- Using HVFA as a partial cement replacement and sugarcane molasses as an admixture in mass concrete construction reduces the consumption of non-renewable materials, saves energy, minimizes CO_2 emissions, and reduces the cost incurred for cement. Therefore, considering the parameters of workability, compressive strength, and water absorption, it can be concluded that a mix with 60% FA and 0.2% molasses dosage is the optimum mix.

5.2 Recommendations

A HVFAC which has proven to be a better alternative than traditional concrete is environmentally friendly and has improved workability, strength and water absorption particularly at an extended late ages. From the findings of the experimental investigation, it has been identified that an incessant and considerable development of compressive strength was observed after 28 days curing period particularly at the age of 56 days. HVFA with molasses adds-in is practically attractive and is recommended for mass concrete structures such as dams and large bridges, building foundations where delayed DEF is of great concern. However, it should be noted that the scope of the current study is limited, as it does not include all mechanical and durability tests for concrete and tests beyond 56 days curing period. Therefore, the following recommendations were forwarded for future investigation.

- The compressive strength test of HVFAC incorporating molasses as an admixture for the late ages than 56-day curing period (90 days, 180 days, and 365 days) need to be conducted to determine the maximum possible strength.
- Optimizing the use of high amount of FA as a cement replacement and molasses as an admixture better be based also on additional concrete properties such as tensile strength, flexural strength, and modulus of elasticity.
- Additional tests other than water absorption test, such as permeability, chloride attack, and sulfur acid attack resistance tests could also be conducted to determine the long-term durability of concrete.

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REFERANCES

Aboustait, M., T. Kim, M. T. Ley, and J. M. Davis. 2016. "Physical and chemical characteristics of fly ash using automated scanning electron microscopy." *Constr. Build. Mater.*, 106: 1–10. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2015.12.098.

Adesina, A. 2020. "Recent advances in the concrete industry to reduce its carbon dioxide emissions." *Environ. Challenges*, 1 (November): 100004. Elsevier B.V. https://doi.org/10.1016/j.envc.2020.100004.

Aïtcin, P. 2016. *Supplementary cementitious materials and blended cements. Sci. Technol. Concr. Admixtures*. Elsevier Ltd.

Akar, C., and M. Canbaz. 2016. "Effect of molasses as an admixture on concrete durability." *J. Clean. Prod.*, 112: 2374–2380. Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2015.09.081.

Ali, B., and L. Ali. 2019. "Durability of recycled aggregate concrete modified with sugarcane molasses." *Constr. Build. Mater.*, 229: 116913. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2019.116913.

Ali, B., L. Ali, Q. Hassan, S. Baig, S. Malik, and M. Din. 2020. "Effect of Molasses and Water – Cement Ratio on Properties of Recycled Aggregate Concrete." *Arab. J. Sci. Eng.*, 45 (5): 3455–3467. Springer Berlin Heidelberg. https://doi.org/10.1007/s13369-019-04117-w.

Alterary, S. S., and N. H. Marei. 2021. "Fly ash properties , characterization , and applications : A review." *J. King Saud Univ. - Sci.*, 33 (6): 101536. The Author(s). https://doi.org/10.1016/j.jksus.2021.101536.

Amran, Y. H. M., M. Gutierrez, R. Alyousef, M. El-zeadani, H. Alabduljabbar, and V. Aune. 2020. "Performance investigation of high-proportion Saudi- fl y-ash-based concrete." *Results Eng.*, 6 (February): 100118. Elsevier Ltd. https://doi.org/10.1016/j.rineng.2020.100118.

Andrew, R. M. 2019. "Global CO 2 emissions from cement production , 1928 – 2018." 1675–1710.

ASTM C33/C33M. 2018. "Standard Specification for Concrete Aggregates." *ASTM Int.*, i (C): 1–11. https://doi.org/10.1520/C0033.

ASTM C618. 2019. "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete." *ASTM Int.*, (C): 3–6. https://doi.org/10.1520/C0618-19.2.

Ban, C., L. Ling, E. Poh, and C. Wei. 2019. "The engineering performance of concrete containing high volume of ground granulated blast furnace slag and pulverized fly ash with polycarboxylate-based superplasticizer." *Constr. Build. Mater.*, 202: 909–921. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2019.01.075.

Barcelo, L., J. Kline, G. Walenta, and E. Gartner. 2020. "Cement and carbon emissions." 1055–1065.

https://doi.org/10.1617/s11527-013-0114-5.

Bhat, T. A., R. Kumar, M. A. Dar, and J. Raju. 2019. *Effect of Sugarcane Molasses on Properties of Geopolymer Concrete*. Springer International Publishing.

Bhide, S., J. Darshane, D. Shinde, S. Dhokale, P. Deshmukh, Y. Desai, and P. Kodag. 2017. “Effect of Sugarcane Molasses on Compressive Strength and Workability of Fly Ash Mixed Concrete.” 3 (3): 607–612.

Cao, C., W. Sun, and H. Qin. 2019. “The analysis on strength and fly ash effect of roller-compacted concrete with high volume fly ash.” *Cem. Concr. Res.*, 30: 71–75.

Crouch, L. K., R. Hewitt, and B. Byard. 2007. “High Volume Fly Ash Concrete.”

Dharmaraj, R., G. K. Arunvivek, A. Karthick, V. Mohanavel, B. Perumal, and S. Rajkumar. 2021. “Investigation of Mechanical and Durability Properties of Concrete Mixed with Water Exposed to a Magnetic Field.” 2021.

Dinakar, P., M. K. Reddy, and M. Sharma. 2013. “Behaviour of self compacting concrete using Portland pozzolana cement with different levels of fly ash.” *J. Mater.*, 46: 609–616. Elsevier Ltd. https://doi.org/10.1016/j.matdes.2012.11.015.

Dinku, A. 2002. *“Construction Materials - Labratory Manual By Abebe Dinku.” Department of civil engineering faculty of technology, AAU, June 2002*. Addis Ababa.

Du, S., Y. Jiang, J. Zhong, Y. Ge, and X. Shi. 2020. “Surface abrasion resistance of high-volume fly ash concrete modified by graphene oxide : Macro- and micro-perspectives.” *Constr. Build. Mater.*, 237: 117686. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2019.117686.

Dunuweera, S. P., and R. M. . Rajapakse. 2018. “Cement Types , Composition , Uses and Advantages of Nanocement , Environmental Impact on Cement Production , and Possible Solutions.” *Adv. Mater. Sci. Eng.*, 2018.

Gaharwar, C., S. Imd, M. P. Sidhi, A. Singh, N. Gaurav, A. P. Singh, and H. Singh. 2016. “A Review Article on Manufacturing Process of Cement , Environmental A Review Article on Manufacturing Process of Cement , Environmental Attributes , Topography and Climatological Data Station : IMD , Sidhi M . P .” *J. Med. Plants Stud.*, (November 2018).

Gardarsdottir, S. O., E. De Lena, M. Romano, S. Roussanaly, M. Voldsund, P. Jos, D. Berstad, C. Fu, R. Anantharaman, D. Sutter, M. Gazzani, M. Mazzotti, and G. Cinti. 2019. “Comparison of Technologies for CO 2 Capture from Cement Production — Part 2 : Cost Analysis.” *MDPI*. https://doi.org/10.3390/en12030542.

Gashaahun, A. D. 2020. “Assessment on Cement Production Practice and Potential Cement Replacing Materials in Ethiopia Assessment on Cement Production Practice and Potential

Cement Replacing Materials in Ethiopia.” (January). https://doi.org/10.7176/CER/12-1-03.

Ge, J. C., S. K. Yoon, and N. J. Choi. 2018. “Application of Fly Ash as an Adsorbent for Removal of Air and Water Pollutants.” *MDPI*. https://doi.org/10.3390/app8071116.

Gołaszewski, J., T. Ponikiewski, and A. Kostrzanowska-siedlarz. 2020. “The Influence of Calcareous Fly Ash on the.”

Gorai, S. 2018. “Utilization of Fly ash for sustainable environment management.” 2508 (2): 385–393.

Gupta, C. 2019. “Tribhuvan University Institute of Engineering Article on EFFECT OF GRADE OF CEMENT ON Chandan Gupta Pulchowk Campus.” (January).

Habert, G., S. A. Miller, V. M. John, J. L. Provis, A. Favier, A. Horvath, and K. L. Scrivener. 2020. “Environmental impacts and decarbonization strategies in the cement and concrete industries.” *Nat. Rev. Earth Environ.*, 1 (11): 559–573. Springer US. https://doi.org/10.1038/s43017-020-0093-3.

Herath, C., C. Gunasekara, D. W. Law, and S. Setunge. 2020. “Performance of high volume fly ash concrete incorporating additives : A systematic literature review.” *Constr. Build. Mater.*, 258: 120606. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2020.120606.

Herath, C., C. Gunasekara, D. W. Law, and S. Setunge. 2021. “Long term creep and shrinkage of nano silica modified high volume fly ash concrete.” *J. Sustain. Cem. Mater.*, 11 (3): 202–222. Taylor & Francis. https://doi.org/10.1080/21650373.2021.1913660.

Hoang, N.-D., and A.-D. Pham. 2016. “Estimating Concrete Workability Based on Slump Test with Least Squares Support Vector Regression.” *J. Constr. Eng.*, 2016: 1–8. https://doi.org/10.1155/2016/5089683.

Huang, G., D. Pudasainee, R. Gupta, and W. Victor. 2020. “Utilization and performance evaluation of molasses as a retarder and plasticizer for calcium sulfoaluminate cement-based mortar.” *Constr. Build. Mater.*, 243: 118201. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2020.118201.

Ikkurthi, S. K., and B. C. J. Kanneganti. 2017. “COMPARATIVE STUDY ON COMPRESSIVE STRENGTH OF FLY ASH CONCRETE.” *Int. J. Civ. Eng. Technol.*, (January).

Justnes, H. 2015. “How to Make Concrete More Sustainable.” *J. Adv. Concr. Technol.*, 13 (March): 147–154. https://doi.org/10.3151/jact.13.147.

Kabir, A., M. Hasan, and K. Miah. 2013. “Strength Prediction Model for Concrete.” (August).

Kara, P., D. Maeijer, B. Craeye, R. Snellings, H. Kazemi-kamyab, M. Loots, K. Janssens, and G. Nuyts. 2020. “Effect of ultra-fine fly ash on concrete performance and durability.” *Constr.*

Build. Mater., 263: 120493. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2020.120493.

Karim, M. R., M. F. M. Zain, M. Jamil, F. C. Lai, and M. N. Islam. 2011. "Strength development of mortar and concrete containing fly ash : A review." 6 (17): 4137–4153. https://doi.org/10.5897/IJPS11.232.

Kassa, Y. 2019. "Application of cane molasses as concrete retarder admixture." *SN Appl. Sci.*, 1 (12): 1–7. Springer International Publishing. https://doi.org/10.1007/s42452-019-1608-8.

Keshavarz, Z., and D. Mostofinejad. 2019. "Porcelain and red ceramic wastes used as replacements for coarse aggregate in concrete." *Constr. Build. Mater.*, 195: 218–230. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2018.11.033.

Khodair, Y., and B. Bommareddy. 2017. "Self-consolidating concrete using recycled concrete aggregate and high volume of fly ash , and slag." *Constr. Build. Mater.*, 153: 307–316. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2017.07.063.

Kim, T., M. T. Ley, S. Kang, J. M. Davis, and S. Kim. 2020. "Using particle composition of fly ash to predict concrete strength and electrical resistivity." *Cem. Concr. Compos.*, 107 (September 2019): 103493. Elsevier Ltd. https://doi.org/10.1016/j.cemconcomp.2019.103493.

Kovler, K., and N. Roussel. 2011. "Cement and Concrete Research Properties of fresh and hardened concrete." *Cem. Concr. Res.*, 41 (7): 775–792. Elsevier Ltd. https://doi.org/10.1016/j.cemconres.2011.03.009.

Kumar, B., G. K. Tike, and P. K. Nanda. 2007. "Evaluation of Properties of High-Volume Fly-Ash Concrete for Pavements." (October): 906–912.

Kumar, D., R. Kumar, and M. Abbass. 2016. "Study The Effect of Coal Bottom Ash on Partial Replacement of Fine Aggregate in Concrete With Sugarcane Molasses as an Admixture." *Int. J. Sci. Res. Educ.*, 4 (5): 5355–5362. https://doi.org/http://dx.doi.org/10.18535/ijsre/v4i05.10 Study.

L.Wilson, and H. K. 2011. *Design and Control of Concrte Mixtures*.

Li, H., Z. Jiang, X. Yang, L. Yu, G. Zhang, J. Wu, and X. Liu. 2015. "Sustainable Resource Opportunity for Cane Molasses: Use of Cane Molasses as a Grinding Aid in the Production of Portland Cement." *J. Clean. Prod.* Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2015.01.027.

Mahmood, H. F., H. Dabbagh, and A. Mohammed. 2020. "Natural Admixture As An Alternative for Chemical Admixture in Concrete Technology: A Review." *J. Univ. Duhok*, (December). https://doi.org/10.26682/csjuod.2020.23.2.24.

Mahmood, H. F., H. Dabbagh, and A. A. Mohammed. 2021. "Comparative study on using chemical and natural admixtures (grape and mulberry extracts) for concrete." *Case Stud. Constr. Mater.*, 15 (September): e00699. Elsevier Ltd. https://doi.org/10.1016/j.cscm.2021.e00699.

Makul, N. 2020. "Modern sustainable cement and concrete composites : Review of current status , challenges and guidelines." *Sustain. Mater. Technol.*, 25: e00155. Elsevier B.V. https://doi.org/10.1016/j.susmat.2020.e00155.

Mclellan, B. C., R. P. Williams, J. Lay, A. Van Riessen, and G. D. Corder. 2019. "Costs and carbon emissions for geopolymer pastes in comparison to ordinary portland cement." *J. Clean. Prod.*, 19 (9–10): 1080–1090. Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2011.02.010.

Mehedi, H. M. A. M., H. Bhuiyan, and N. Jahan. 2020. "Influence of delayed casting on compressive strength of concrete : an experimental study." *SN Appl. Sci.*, 2 (3): 1–7. Springer International Publishing. https://doi.org/10.1007/s42452-020-2135-3.

Miller, S. A., A. Horvath, and P. J. M. Monteiro. 2019. "Readily implementable techniques can cut annual CO 2 emissions from the production of concrete by Readily implementable techniques can cut annual CO 2 emissions from the production of concrete by over 20 %." IOP Publishing.

Mohamed, A. M., and R. Khallaf. 2022. "Fly Ash Application as Supplementary Cementitious Material : A Review." 1–23.

Moropoulou, A., A. Bakolas, and E. Aggelakopoulou. 2004. "Evaluation of pozzolanic activity of natural and artificial pozzolans by thermal analysis." 420: 135–140. https://doi.org/10.1016/j.tca.2003.11.059.

Muritala, E., A. Adigun, B. Eng, and M. Sc. 2013. "Cost Effectiveness of Replacing Sand with Crushed Granite Fine (CGF) In the Mixed Design of Concrete." 10 (1): 1–6.

Oyebisi, S., F. Olutoge, P. Kathirvel, I. Oyaotuderekumor, D. Lawanson, J. Nwani, and A. Ede. 2022. "Sustainability assessment of geopolymer concrete synthesized by slag and corncob ash." *Case Stud. Constr. Mater.*, 17 (August): e01665. Elsevier Ltd. https://doi.org/10.1016/j.cscm.2022.e01665.

P. Mehta and J. Monteiro. 2014. *Concrete Microstructure, Properties, and Materials*.

Panda, L., and S. Dash. 2019. "Characterization and utilization of coal fly ash : a review." *Emerg. Mater. Res.*, (Figure 1): 1–14.

Patel, G. K., and S. V Deo. 2016. "Effect of Natural Organic Materials as Admixture on Properties of Concrete." *Indian J. Sci. Technol.*, 9 (October). https://doi.org/10.17485/ijst/2016/v9i37/93541.

Pathan, S. B. 2017. "Using Molasses in Concrete As A Time Retarding Admixture." *Int. J. Eng. Res. Technol.*, 6 (11): 509–513.

Pizon, J., B. Ła´zniewska-Piekarczyk, and P. Miera. 2022. "The Influence of the Acceleration

Admixture Type and Composition of Cement on Hydration Heat and Setting Time of.” *MDPI*.

Rashid, K., S. Tariq, and W. Shaukat. 2019. “Attribution of molasses dosage on fresh and hardened performance of recycled aggregate concrete.” *Constr. Build. Mater.*, 197: 497–505. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2018.11.249.

Rivera, F., P. Martínez, J. Castro, and M. López. 2015. “‘Massive Volume Fly-Ash Concrete: A More Sustainable Material with Fly Ash Replacing Cement and Aggregates.’” *Cem. Concr. Compos.* Elsevier Ltd. https://doi.org/10.1016/j.cemconcomp.2015.08.001.

Rouch, D. A. 2022. “Cement and concrete manufacturing future: better reducing greenhouse gas emissions.” (March).

Sathyan, D., and K. B. Anand. 2019. “Influence of superplasticizer family on the durability characteristics of fly ash incorporated cement concrete.” *Constr. Build. Mater.*, 204: 864–874. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2019.01.171.

Schneider, M. 2019. “The cement industry on the way to a low-carbon future.” *Cem. Concr. Res.*, 124 (June): 105792. Elsevier. https://doi.org/10.1016/j.cemconres.2019.105792.

Serte, A. T. 2019. “IMPACT OF SUGARCANE MOLASSES IN CONCRETE AS TIME Retarding and Water Reducing Admixture.” *Addis Ababa Sci. Technol. Univ.*, (October).

Snellings, R., G. Mertens, and J. Elsen. 2012. “Supplementary Cementitious Materials.” 74 (Blezard 2001): 211–278. https://doi.org/10.2138/rmg.2012.74.6.

Suraneni, P., and J. Weiss. 2017. “Examining the pozzolanicity of supplementary cementitious materials using isothermal calorimetry and thermogravimetric analysis.” *Cem. Concr. Compos.* Elsevier Ltd. https://doi.org/10.1016/j.cemconcomp.2017.07.009.

Tuan, N. M., Q. Van Hau, S. Chin, and S. Park. 2021. “In-situ concrete slump test incorporating deep learning and stereo vision.” *Autom. Constr.*, 121 (October 2020): 103432. Elsevier B.V. https://doi.org/10.1016/j.autcon.2020.103432.

Tydlitát, V., P. Svora, and C. Robert. 2018. “Physical and chemical characterization of technogenic pozzolans for the application in blended cements.” 160: 106–116. https://doi.org/10.1016/j.conbuildmat.2017.11.021.

Vora, P. R., and U. V Dave. 2013. “Parametric Studies on Compressive Strength of Geopolymer Concrete.” *Procedia Eng.*, 51: 210–219. Elsevier B.V. https://doi.org/10.1016/j.proeng.2013.01.030.

Wang, K. 2017. *Sustainable Development and Concrete Technology*.

Wang, P., N. Gao, K. Ji, L. Stewart, and C. Arson. 2020. “DEM analysis on the role of aggregates on concrete strength.” *Comput. Geotech.*, 119 (October).

https://doi.org/10.1016/j.compgeo.2019.103290.

Wang, T., T. Ishida, and R. Gu. 2018. "A comparison of the specific surface area of fly ash measured by image analysis with conventional methods." *Constr. Build. Mater.*, 190: 1163–1172. https://doi.org/10.1016/j.conbuildmat.2018.09.131.

Waqas, R. M., F. Butt, X. Zhu, T. Jiang, and R. F. Tufail. 2021. "applied sciences A Comprehensive Study on the Factors Affecting the Workability and Mechanical Properties of Ambient Cured Fly Ash and Slag Based Geopolymer Concrete."

Warati, G. K., M. M. Darwish, F. F. Feyessa, and T. Ghebrab. 2019. "Suitability of Scoria as Fine Aggregate and Its E ff ect on the Properties of Concrete."

Weifeng, L. I., M. A. Suhua, and Z. Shengbiao. 2014. "Physical and chemical studies on cement containing sugarcane molasses." 83–91. https://doi.org/10.1007/s10973-014-3947-4.

Wongkeo, W., P. Thongsanitgarn, A. Ngamjarurojana, and A. Chaipanich. 2014. "Compressive strength and chloride resistance of self-compacting concrete containing high level fly ash and silica fume." *J. Mater.* Elsevier Ltd. https://doi.org/10.1016/j.matdes.2014.07.042.

Xu, G., and X. Shi. 2018. "Resources , Conservation & Recycling Characteristics and applications of fl y ash as a sustainable construction material : A state-of-the-art review." *Resour. Conserv. Recycl.*, 136 (August 2017): 95–109. Elsevier. https://doi.org/10.1016/j.resconrec.2018.04.010.

Xu, W., L. Liang, and M. Zhu. 2015. "Determination of Sugars in Molasses by HPLC Following Solid-Phase Extraction." *Int. J. Food Prop.*, 18 (3): 547–557. Taylor & Francis. https://doi.org/10.1080/10942912.2013.837064.

Yang, G., T. Wu, C. Fu, and H. Ye. 2021a. "Effects of activator dosage and silica fume on the properties of Na 2 SO 4 -activated high-volume fly ash." *Constr. Build. Mater.*, 278: 122346. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2021.122346.

Yang, L., X. An, and S. Du. 2021b. "Estimating workability of concrete with different strength grades based on deep learning." *Meas. J. Int. Meas. Confed.*, 186 (August): 110073. Elsevier Ltd. https://doi.org/10.1016/j.measurement.2021.110073.

Yildirim, H., and B. Altun. 2012. "Usage of molasses in concrete as a water reducing and retarding admixture." 19 (December): 421–426.

Yoshitake, I., H. Komure, A. Y. Nassif, and S. Fukumoto. 2013. "Tensile properties of high volume fly-ash (HVFA) concrete with limestone aggregate." *Constr. Build. Mater.*, 49: 101–109. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2013.08.020.

Zhang, D., J. Zhao, D. Wang, Y. Wang, and X. Ma. 2020. "Influence of pozzolanic materials on the properties of natural hydraulic lime based mortars." *Constr. Build. Mater.*, 244: 118360.

Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2020.118360.

Zhao, Z., K. Wang, D. A. Lange, H. Zhou, W. Wang, and D. Zhu. 2019. "Creep and thermal cracking of ultra-high volume fl y ash mass concrete at early age." *Cem. Concr. Compos.*, 99 (July 2017): 191–202. Elsevier. https://doi.org/10.1016/j.cemconcomp.2019.02.018.

Zin, T., S. Bonnet, and S. H. Gheewala. 2021. "Emission reduction pathways for a sustainable cement industry in Myanmar." *Sustain. Prod. Consum.*, 27: 449–461. Elsevier B.V. https://doi.org/10.1016/j.spc.2021.01.016.

Ziolkowski, P., and M. Niedostatkiewicz. 2019. "Machine learning techniques in concrete mix design." *Materials (Basel).*, 12 (8). https://doi.org/10.3390/ma12081256.

Zongjin, L. 2011. *Advanced Concrete Technology Advanced Concrete Technology*.

APPENDIX

Appendix A: Tables for ACI Based Concrete Mix Design Processes

Appendix A1: Average Compressive strength Conversion Factors based on the grade Of concrete

Specified characteristic Compressive strength (fck, MPa)	Required mean compressive strength in (F'ck , MPa)
< 21	fck +7
21-35	fck +8.5
>35	1.1 x fck +5

Appendix A2: Approximate mixing water and air content requirements

Slump, cm	Water kg/m^3 of concrete for indicated max. sizes of aggregate in mm							
	10	12.5	20	25	40	50	70	150
Non-air entrained concrete								
2 -10	205	200	185	180	160	155	145	25
8 - 10	225	215	200	195	175	170	160	140
15 - 18	240	230	210	205	185	180	170	-
Approx. Amount of Entrapped air in non-entrained concrete (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air entrained concrete								
3 – 5	180	175	165	160	145	140	135	120
8 – 10	215	206	190	185	170	165	160	-
Recommended average total air content (%)	8	7	6	5	4.5	4	3.5	3

Appendix A3: Relationships between water-cement ratio and compressive strength of Concrete.

Compressive strength at 28 days (MPa)	Water cement ratio by mass	
	Non-air entrained	Air entrained
45	0.38	-
40	0.42	-
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.71

Appendix A4: Volume of coarse Aggregate per unit Volume of concrete

Maximum size of aggregate, mm	Volume of dry rodded coarse aggregate per unit volume of concrete for different fineness modulus of fine aggregate			
	2.4	2.6	2.8	3.0
10	0.48	0.50	0.46	0.44
12.5	0.57	0.59	0.55	0.53
20	0.64	0.66	0.62	0.60
25	0.69	0.71	0.67	0.65
40	0.73	0.76	0.72	0.70
50	0.76	0.78	0.74	0.72
70	0.80	0.81	0.77	0.75
150	0.85	0.87	0.83	0.81

Appendix B: Different Test Procedures for Various Conducted Experimental Tests

Appendix B1: Test Procedures for Silt Content Test [ASTM C117 (2017)]

1. The researcher took a graduated cylinder having a capacity of 1000 ml.
2. 300 ml of sand was poured into the cylinder.
3. Approximately 3/4 of the jar was filled with water.
4. The jar was shaken vigorously for about a minute.
5. The jar was left for an hour to allow the silt to settle on the layer of sand.
6. The amount of fine forming a separate layer on the top was measured and then silt content was calculated

Appendix B2: Procedure for Grading Fine Aggregate [ASTM C136 (2006)]

1. The researcher weighted a sample of 2 kg of fine aggregates.
2. The sample was quartered.
3. From the quartered sample, 500 g was taken,
4. The empty sieves were weighted, and the data was recorded properly.
5. The pan was placed on the bottom and the other sieves were put on the pan with increasing opening sizes of the sieves.
6. The 500 g of sample was placed on the top of the sieves (having a larger opening size).
7. The sample was smashed for about 10 minutes in a sieve shaker.
8. Each sieve, together with the aggregate retained on it, was measured and the weight retained on each sieve was calculated.
9. The gradation chart was filled in and the fineness modulus was computed

Appendix B3: Procedure for Grading Coarse Aggregate [ASTM C136 (2006)]

1. 20 kg of coarse aggregates was weighed.
2. A representative sample was selected by quartering.
3. From the quartered sample, 2 kg was taken.
4. The empty sieves were weighted and the data was recorded properly.
5. The 2 kg of sample was placed on the top sieves (which have a large opening size).
6. The sample was smashed for about 10 minutes in a sieve shaker.
7. Each sieve, together with the aggregate retained on it, was measured and the weight retained on each sieve was calculated.
8. The gradation chart was filled in and the Fineness Modulus (F.M.) was computed

Appendix B4: General Procedures Followed for Wet sieve Analysis of FA [ASTM C136 (2006)]

1. 200g dry sample passing 75μm sieve was weighed to the nearest 0.1g
2. The sample was then placed on the sieve no. 325 (45micron)
3. Then the sample was washed back and forth using gentle, controlled water pressure to prevent accidental sample loss
4. The sample was rinsed with water and agitated by hand until the water running through the sieve is clear.
5. Then, the FA retained on the no. 325 sieve was collected and dried in an oven at 110 ± 5^{o}C until constant weight is achieved

6. Then, the dried sample weight was recorded
7. Finally, the percentage of FA retained on the sieve was calculated by dividing the weight of the retained FA by the initial sample mass and multiply by 100.

Appendix B5: Specific Gravity and Water Absorption Test Procedures of Fine Aggregate [ASTM C128 (2015)]

Preparation of the Test Specimen:

1. Approximately 1 kg of the fine aggregate was prepared.
2. At 110°C, the sample was dried to a constant weight in a suitable pan and it was allowed it to cool for 24 hours and then make it saturated.
3. The excess water was decanted with care to avoid loss of fines, spreading the sample on a flat, non-absorbent surface exposed to a gently moving current of warm air.
4. The sample was stirred frequently to get homogeneous drying until achieving the saturated surface dry condition by using the cone test for surface moisture.
5. The mold was held firmly on a smooth, non-absorbent surface with a large diameter. A portion of partially dried fine aggregate was placed loosely in the mold by filling it to the brim and heaping additional materials above the top of the mold.
6. The sand lightly tamped into the mold with 25 light drops of the tamper about 5 mm above the top surface of the sand.
7. The surface was adjusted by removing loose sand from the base and lifting the mold vertically. If surface moisture was still present, the sand would retain the molded shape. When the sand slumped slightly, it indicated that it had reached S.S.D. condition.

Procedures:

1. The S.S.D sample was weighted at 500 g.
2. The Pycnometer was partially filled with water and 500 g of saturated surface dry aggregates put into the Pycnometer.
3. Then the Pycnometer was filled with additional water to fill it to 90% of its capacity.
4. The Pycnometer was rolled and inverted to eliminate all air bubbles
5. The Pycnometer was placed in a water bath at 23°C for an hour
6. The water level in the Pycnometer was brought to its calibrated capacity.
7. Then, the total weight of the Pycnometer, specimen, and water was measured.

8. The fine aggregate was removed from the Pycnometer, dried to a constant weight at 105 °C, cooled in room temperature air for one hour, and measured
9. The weight of the Pycnometer filled to capacity with water was determined at 23°C, and data were recorded

Appendix B6: Specific Gravity and Water Absorption Test Procedures of Coarse Aggregate [ASTM C127 (2015)]

1. The researcher took the sample of coarse aggregate by using the sample splitter.
2. The sample was sieved with a 4.75 mm sieve, and the sample passing through the 4.75 mm sieve was ignored.
3. The sample was washed to remove dust and then was put in the oven at 105°C for 24 hours.
4. The sample was taken out of the oven, left to cool, and then the weight was measured.
5. The sample was submerged in water for 24 hours.
6. The researcher removed the sample from the water and rolled it in a large absorbent cloth until all visible films of water were removed.
7. The required weight of the sample in its (S.S.D) condition was taken.
8. The researcher immediately placed the S.S.D sample in the sample container, determined the weight in water at 23 °C, and recorded the data.

Appendix B7: Slum test procedures

1. The slump cone was first washed with water and placed on a smooth and flat metal plate to conduct the test.
2. The slump cone was filled with freshly mixed concrete in three different layers.
3. Each layer of the concrete mix was tapped 25 times with a 600 mm long metal rod that was 16 mm in diameter.
4. Extra concrete was removed after filling the last layer from the top of the cone.
5. The slump cone was then quickly lifted upward with two hands. The concrete is then free to fall.
6. After free fall, the remaining height is known as a slump (the difference between the height of the mold and the height of the vertical axis) and was measured.

Appendix C: Detail Results of Different Tests

Appendix C1: Detail slump value for fresh concrete that was blended with FA; for each Mix code three trail was tested.

No	Mix ID	Slump Results (mm)			
		Trial-1	Trial-2	Trial-3	Average (mm)
1	R	29.5	31	29.5	30
2	M40,0.10	35	34.5	35.5	35
3	M40,0.15	37	38	39	38
4	M40,0.20	45.5	46	43.5	42.5
5	M50,0.10	45.5	45.5	44	45
6	M50,0.15	48	46.5	46.5	47
7	M50,0.20	48.5	52	51	50.5
8	M60,0.10	50.5	52.5	53	52
9	M60,0.15	53	54	55	54
10	M60,0.20	58	56.5	56.5	57

Appendix C2: Detail result of compressive strength for different mix code at different Curing periods.

Mix ID	**Sample**	**Compressive strength result in N/mm²**					
		7th day		**28th day**		**56th day**	
		Load (KN)	**Strength**	**Load (KN)**	**Strength**	**Load (KN)**	**Strength**
R	1	659	29.28	847	37.64	880	39.12
	2	650	28.89	856	38.05	839	37.28
	3	652	29.01	851	37.85	870	38.65
	Average	**653**	**29.06**	**851**	**37.85**	**863**	**38.35**
M40,0.10	1	372	16.53	735	32.67	865	38.45
	2	400	17.82	717	31.85	848	37.69
	3	380	16.91	712	31.63	881	39.15
	Average	**384**	**17.09**	**721**	**32.05**	**865**	**38.43**
M40,0.15	1	323	14.35	608	27.01	881	39.15
	2	330	14.67	636	28.25	858	38.14
	3	342	15.22	624	27.72	885	39.35
	Average	**331**	**14.75**	**622**	**27.66**	**875**	**38.88**
M40,0.20	1	209	9.28	566	25.17	917	40.77
	2	224	9.99	583	25.89	925	41.10
	3	201	8.96	581	25.83	896	39.81
	Average	**211**	**9.41**	**577**	**25.63**	**913**	**40.56**
M50,0.10	1	228	10.30	489	21.74	962	42.75
	2	227	10.11	502	22.30	931	41.38
	3	223	9.92	471	20.94	943	41.90
	Average	**226**	**10.11**	**487**	**21.66**	**945**	**42.01**
Mix ID	Sample	**Compressive strength result in N/mm²**					

		7th day		28th day		56th day	
		Load (KN)	**Strength**	**Load (KN)**	**Strength**	**Load (KN)**	**Strength**
M50,0.15	1	248	11.02	486	21.59	966	42.94
	2	265	11.81	469	20.86	983	43.68
	3	254	11.33	493	21.93	976	43.37
	Average	**255**	**11.39**	**483**	**21.46**	**975**	**43.33**
M50,0.20	1	276	12.26	574	25.51	987	43.88
	2	296	13.17	527	23.42	996	44.25
	3	290	12.91	516	22.95	987	43.87
	Average	**287**	**12.78**	**539**	**23.96**	**990**	**44**
M60,0.10	1	198	8.80	483	21.45	1006	44.72
	2	208	9.25	454	20.18	1038	46.13
	3	193	8.61	471	20.92	1008	44.78
	Average	**199**	**8.89**	**469**	**20.85**	**1017**	**45.21**
M60,0.15	1	175	7.77	433	19.22	1010	44.89
	2	180	8.03	457	20.33	1040	46.21
	3	178	7.95	451	20.03	1034	45.94
	Average	**177**	**7.92**	**447**	**19.86**	**1028**	**45.68**
M60,0.20	1	161	7.15	431	19.14	1054	46.84
	2	180	8.01	409	18.16	1079	47.96
	3	165	7.35	410	18.20	1054	46.86
	Average	**168**	**7.50**	**416**	**18.5**	**1062**	**47.22**

Appendix C3: Water absorption result for each sample at different mix code and curing days.

Mix ID	Sample	Water absorption in percent					
		@ 28th day			@ 56th day		
		W_d (kg)	W_s (kg)	W (%)	W_d (kg)	W_s (kg)	W (%)
R	1	0.771	0.841	9.1	0.758	0.824	8.7
	2	0.714	0.786	10.1	0.763	0.799	4.7
	3	0.741	0.773	4.3	0.765	0.837	9.4
	Average	0.742	0.80	**7.8**	0.762	0.820	7.6
M40,0.10	1	0.734	0.794	8.2	0.743	0.797	7.3
	2	0.712	0.784	10.1	0.742	0.787	6.1
	3	0.756	0.810	7.1	0.747	0.810	8.4
	Average	0.734	0.796	**8.4**	0.744	0.798	7.3
M40,0.15	1	0.726	0.798	9.9	0.732	0.798	9.0
	2	0.748	0.777	3.9	0.751	0.797	6.1
	3	0.716	0.801	11.9	0.746	0.793	6.3
	Average	0.730	0.792	**8.5**	0.743	0.796	7.1
M40,0.20	1	0.735	0.781	6.3	0.738	0.798	8.1
	2	0.743	0.798	7.4	0.751	0.796	6.0
	3	0.715	0.806	12.7	0.749	0.800	6.8
	Average	0.731	0.795	**8.8**	0.746	0.798	7.0
M50,0.10	1	0.710	0.789	11.1	0.743	0.791	6.5
	2	0.731	0.784	7.3	0.738	0.790	7.0
	3	0.725	0.791	9.1	0.745	0.795	6.7
	Average	0.722	0.788	**9.2**	0.742	0.792	6.8
Mix ID	Sample	**Water absorption in percent**					

		@ 28th day			@ 56th day		
		W_d (kg)	W_s (kg)	W (%)	W_d (kg)	W_s (kg)	W (%)
M50,0.15	1	0.723	0.768	6.2	0.739	0.793	7.3
	2	0.718	0.787	9.6	0.744	0.785	5.5
	3	0.704	0.791	12.4	0.737	0.786	6.7
	Average	0.715	0.782	**9.4**	0.740	0.788	6.5
M50,0.20	1	0.712	0.772	8.4	0.733	0.784	7.0
	2	0.710	0.780	9.9	0.743	0.779	4.9
	3	0.705	0.782	10.9	0.729	0.780	7.0
	Average	0.709	0.778	**9.8**	0.735	0.781	6.3
M60,0.10	1	0.712	0.792	11.2	0.729	0.779	6.9
	2	0.717	0.785	9.5	0.741	0.773	4.3
	3	0.710	0.796	12.1	0.726	0.779	7.3
	Average	0.713	0.791	**11**	0.732	0.777	6.1
M60,0.15	1	0.700	0.786	12.3	0.728	0.773	6.2
	2	0.698	0.790	13.2	0.734	0.771	5.0
	3	0.705	0.782	10.9	0.728	0.778	6.9
	Average	0.701	0.786	**12.1**	0.730	0.774	6.0
M60,0.20	1	0.707	0.793	12.2	0.721	0.767	6.4
	2	0.704	0.790	12.2	0.736	0.766	4.1
	3	0.716	0.811	13.3	0.724	0.774	6.9
	Average	0.709	0.798	**12.6**	0.727	0.769	5.8

Appendix D: Oxide Composition of Fly Ash

	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name:- Kumera Daka and Zewudu Sileshi

Sample type :-Synthetic

Sample Preparation: -200 Mesh

Date Submitted:- 14/03/2023

Issue Date:-24/03/2023

Request No:- GLD/RQ/964/23

Report No:- GLD/RN/1585/23

Number of Sample:- One (01)

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
FAD-5	49.34	30.53	3.02	0.14	0.24	<0.01	0.62	<0.01	0.17	0.67	1.32	11.14	250 gm

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

Analysts	Checked By	Approved By	Quality Control
Haimanot Bayeh Gadisa Wakuma Nigist Fikadu	Lidet Endeshaw	Yohannes Getachew	Negash Worku

Appendix E: Pictures taken during experimental works

Appendix E1: Pictures captured during normal consistency and setting time test

Appendix E2: Pictures captured during slump test

Appendix E3: Captured pictures of Casted Concrete Samples: (150*150*150) mm sized cube for compressive strength test and (70*70*70) mm sized cube for water absorption test.

Appendix E4: Pictures taken during demoulding and then curing of different concrete Samples in the curing tank.

Appendix E5: Pictures taken during sample preparation for compressive strength test and During conducting the test.

Appendix E6: Pictures taken during oven drying, weighing and submerging samples in . Water for water absorption test.