ADDIS ABEBA UNIVERSITY

COLLEGE OF TECHNOLOGY AND BUILT ENVIRONMENT

SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING

Partial Replacement of Cement with Municipal Solid Waste Incinerator Fly Ash in Concrete Production

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A Thesis in Structural Engineering

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The undersigned have examined the thesis entitled '**Partial Replacement of Cement with Municipal Solid Waste Incinerator Fly Ash in Concrete Production**' presented by **Merem Sualih**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I confirm that research work titled "**Partial Replacement of Cement with Municipal Solid Waste Incinerator Fly Ash in Concrete Production**" is my own work. The work has not been presented elsewhere for assessment. Where material used from other sources has been properly referred.

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ABSTRACT

Fly ash resulting from municipal solid wastes incinerator (MSWI) can be potentially reused as cement replacement in concrete. However, several researchers suggest that fly ash requires pre-treatment due to its high chlorine content to be used as partial substitute for cement in concrete. Currently large amount of fly ash is generated in thermal power plant as waste material with an improper impact on environment and humans in Ethiopia. Fly ash waste generated by Reppie thermal power plant is as such a big environmental concern.

This research examines the potential of using treated and untreated MSWI fly ash as partial replacement of cement in concrete production for saving waste disposal cost, conserving natural resource and for mitigating the environmental impact of cement production. This study aim to investigate early and late age mechanical and durability properties of untreated and treated fly ash concrete. In this research, the fly ash was treated by washing with water only to reduce the chlorine and sulfur.

Concrete mixture containing 0%, 10%, 15%, and 20% dosage of untreated and treated fly ash by volume were proportioned. The compressive and flexural based tensile strength result at three, seven, twenty-eight and fifty-six days and also the water permeability data for twenty-eight days are determined. The experimental outcome indicates that the compressive strength of treated fly ash is lower compared to untreated fly ash, but still fall with in an acceptable range when compared to the control mix. The compressive strength of washed fly ash concrete with 10% and 15% replacement ratio exceed the control group's 28^{th}-day strength by 0.15% and 3.78% respectively. However, the flexural strength decreases as the level of both washed and unwashed fly ash increase. Still, the washed fly ash at 10% and 15% replacement level exhibits acceptable result when compared to the control group. Moreover, the 10% and 15% washed fly ash replaced concrete sample possess a better water tightness performance than the controlled sample. Based on the result, the treated FA can replace cement up to 15%.

Key words: Municipal solid waste incineration, Treated fly ash, Partial replacement, mechanical properties, durability.

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LIST OF ABBREVIATION

MSWI	Municipal Solid Waste Incinerator
FA	Fly Ash
OPC	Ordinary Portland Cement
AAiT	Addis Ababa Institute of Technology
ASTM	American Standard Testing Material
ACI	American Concrete Institute
C–S–H	Calcium Silicate Hydrate
LOI	Loss of Ignition
MPa	Mega Pascal
SCM	Supplementary Cementitious Materials
XRD	X-Ray Diffraction
WFA	Washed Fly Ash
UNWFA	Unwashed Fly Ash

1. INTRODUCTION

1.1 Background

In the construction industry, concrete is one of the most popular construction material. Due to this reason there is an increasing demand for cement both in building and infrastructure development.

The main environmental challenge faced by the cement industry is CO_2 emission. Main pollutions of cement productions include; cement dust, air pollution, water pollution, solid waste pollution, noise pollution, ground vibration and resource depletion due to raw material extraction [1]. Cement production is one of the main pollution contributors due to its extensive energy consumption and gas emission. It is produced by heating calcium (usually limestone) silica, alumina (typically clay or shale) and iron (steel mill scale or iron ore) in cement kilns [1].

The ordinary Portland cement production process consists of the following main steps:

1. preparation of a material mixture consisting of mainly limestone, clay, sand, and iron oxides;
2. pre-cacining in the pre-heating system to initiate the dissociation of calcium carbonate to calcium oxide and carbon dioxide and subsequent burning of the material mixture in the cement kiln at a temperature of up to 1450 °C to produce Portland cement clinker;
3. Grinding and mixing of the cooled Portland cement clinker with small amounts of calcium sulfate like gypsum or anhydrite, resulting in OPC [2].

Greenhouse gases are produced directly from fuel consumption and additional cement production process itself releases CO_2 when the calcium carbonate in lime stone is converted to calcium oxide during the production of clinker in kiln. Also, 0.613 ton of CO_2 emission from one ton of clinker is produced [1].at least 5 percent of humanity's carbon footprint comes from the concrete industry [3]. As environmental concerns escalate and the demand for sustainable practices grows, exploring alternative material to reduce the carbon footprint of concrete production becomes increasingly important.

Particularly with regard to cement replacement programs, there is currently a greater interest in substituting construction raw materials with alternative materials in order to reduce construction costs and save natural resources. Since the production of one tone of Portland cement produces roughly the same amount of carbon dioxide (CO_2), research has focused on a variety of waste materials that could be used as sources, including recycled concrete, post-consumer glass, recycled tires, recycled plastics, waste ceramics, waste bricks, cork, municipal solid waste and more [4]. The sustainability of the construction sector can be raised by using these materials partially in substitute of cement.

Due to the massive amounts of municipal solid waste that are produced today as a result of consumer society, mass production, and consumption of goods, incineration is used to reduce mass and volume, which is crucial for waste management and environmental protection. The most efficient method for managing waste and preserving landfill space is incineration, which results in a 70% mass reduction and a 90% volume reduction [5].

However, it is not a final solution, as it generates by-products such as bottom ash and fly ash that must be disposed of. Bottom ash collected at the base of the combustion chamber consists of slag-like material, while fly ash, the finer fraction is captured from the flue gas by air pollution control (APC) device and poses more significant environmental challenges. Fly ash contains fine particles with leachable heavy metals, soluble salts particularly alkali metal chlorides and is therefore classified as toxic waste [6]. These factors make fly ash management a critical environmental issue associated with municipal solid waste (MSW) incineration. Fly ash also possesses pozzolanic properties and contains typical cement raw material such as silicates, quartz, aluminosilicates, and lime which means it could potentially be used in construction materials after appropriate treatment [6].

Reppi Waste to electricity Power Plant was built by Ethiopia Electric Power Authority and the Addis Ababa City Administration to use municipal solid waste as a source of renewable electricity. Reppi waste to Energy disposal facility, which is 13 kilometers from Addis Ababa's city center, can dispose of 420,000 tons of waste annually and is utilized to generate renewable electricity for the city of Addis Ababa (Reppie waste to energy, 2014). Even though this power plant utilized this MSW to produce useable electricity, it would still produce waste (bi-products) that would need a sizable disposal area and have an impact on the echo system. Fly ash and bottom ash are two different types of wastes generated by this plant.

Fly ash is an inexpensive replacement for Portland cement used in concrete, while it actually improves strength, and ease of pumping of the concrete. Fly ash is also used as an ingredient in brick, block, paving, and structural fills [7].

The Reppie waste to energy power plant generates $15.21*10^3$ tons of fly ash per year, which is currently dumped in landfills nearby. This requires a constant business that transforms/uses this by product into a usable ingredient [8]. This paper aims to provide comprehensive understanding of how fly ash can influence concrete performance and contribute to more sustainable construction practice. Special attentions are paid on the treatment of fly ash to remove impurities and the utilization of fly ash in concrete mix.

1.2 Statement of the problem

The construction industry is a significant consumer of cement, a major contributor to CO_2 emission due to its production processes. With the increasing global focus on sustainable practices and waste management, there is a growing need to explore alternative materials that can reduce the environmental impact of concrete production.

MSWI FA has emerged as a potential candidate for partial replacement of cement in concrete due to its availability and potential for reducing waste volume. However the impact of MSWI FA on the mechanical properties, durability and overall performance of concrete is rarely investigated. This research aim to investigate the feasibility of using treated MSWI FA as partial substitute for cement in concrete, focusing on how it affect the strength, workability, and long term durability of concrete. The outcome will provide valuable insight into the viability of integrating MSWI FA in to concrete production, contributing to more sustainable construction practices and improve waste management strategies.

1.3 Objectives of the study

1.3.1 General objectives

The primary objective of this study is to investigate the effect of using Reppie waste to energy power plant bi-product, FA, as partial replacement of cement for production of concrete.

1.3.2 Specific objectives

The specific objectives of this study are:-

- To examine the chemical composition of untreated and treated municipal solid waste fly ash.
- To study the influence of percentage replacement of cement by municipal solid waste fly ash on the physical and chemical properties of Portland cement on normal strength concrete.
- To determine the workability of concrete when cement is partially replaced with municipal solid waste fly ash at different percentages.
- To evaluate the compressive strength, flexural strength and water tightness of hardened concrete when cement is partially replaced with treated and untreated municipal solid waste fly ash at different percentages.

1.4 Scope of the study

- In this research, the role of municipal solid waste fly ash partially blended with cement for achieving the optimal and standard normal strength concrete requirements using different concrete tests were investigated.
- The study aim to investigate the effect of MSWI fly ash as SCM, evaluating its impact on the mechanical and durability properties of concrete.
- Due to the presence of chlorine and sulfur in MSWI fly ash, this research applying appropriate treatments to make it suitable for use as a partial replacement of cement in concrete.
- The study is limited to normal strength mixes with replacement levels typically ranging from 0% to 20% by volume of cement.

- Because of budget limitations and the intention to examine concrete properties over abroad age range (3, 7, 28, and 56 days) only two cubes were tested per sample at each testing age.

1.5 Research Motivation

Cement is one of the most widely used construction material, but its production comes with serious environmental and economic challenges. It emits a large amount of carbon dioxide, consumes high levels of energy, and relies on natural raw materials like limestone and clay, which are being rapidly depleted. Additionally, the cost of cement continues to rise, making construction more expensive especially in developing countries.

At the same time, the Reppie waste to energy power plant in Addis Ababa, Ethiopia, generates large amount of MSWI fly ash as a byproduct of burning household and municipal waste. This ash is often treated as waste and disposed of in landfills, which can cause environmental harm. However, MSWI fly ash may have potential value as a partial replacement for cement in concrete production.

This research is motivated by the opportunity to address two major environmental issues at once: reducing the negative impacts of cement production and finding a sustainable use for MSWI fly ash generated by the Reppie waste to energy plant. By partially replacing cement with this fly ash, the study aim to reduce greenhouse gas emissions, lower construction costs, conserve natural resources, and support waste recycling. This study investigated the effect of using MSWI fly ash from Reppie on the strength, durability, and overall performance of concrete. The intended field of application includes general construction and infrastructure projects such as roads, pavements, low-rise buildings, and non-structural elements where eco-friendly materials can be safely and effectively used.

1.6 Organization of the Thesis

The five chapters of the thesis are organized as follows. Chapter one provides a basic introduction to the thesis along with some background information. It also discusses the justification of the research by highlighting the main difficulties associated with the partial substitution of municipal solid waste fly ash for cement as well as the thesis's objectives, scope, and structure. The second chapter covers the relevant literature and quotes from several related publications in the field. The materials, techniques, and testing procedures are presented in the third chapter. The fourth chapter tries to summarize the outcomes of the tests in detail, followed by a discussion of the findings. Finally, the study's conclusion and recommendation are presented in Chapter 5.

2 LITERATURE REVIEW

2.1 Introduction

In this chapter, the review of relevant literature on cement replacement, waste materials and partial replacement of cement with municipal solid waste incinerator fly ash are discussed.

2.2 Concrete

Concrete is mainly a combination of two ingredients. Portland cement with water making the paste is the first main ingredient. The paste constitutes about 25% to 40% of the total volume of concrete. The second main ingredients are aggregates which are typically sand and gravel or crushed stone. The paste hardens and binds the aggregates into a rocklike mass as the cement and water react chemically. The paste and aggregate including the bond in between them determines the quality of the concrete. The aggregate particles are completely coated and all of the spaces in between them with paste in a suitably prepared concrete. The quality of the paste and aggregate merged with the bond between the two determines the quality of the concrete in general [9].

The amount of water used in relation to the amount of cement used in hardened concrete is strongly influenced by the amount of water used in relation to the amount of cement used in any particular set of materials and curing conditions. Unnecessarily high water contents dilute the glue of concrete which is cement paste. The higher the quality of the concrete, the less water it takes to make it. Smaller amounts of mixing water result in stiffer mixtures; but with vibration, stiffer mixtures can be easily placed.

2.2.1 Components of Concrete

The main components of concrete are cement, fine aggregate, coarse aggregate and water.

2.2.1.1 Cement

Cements are adhesive compounds that may bind together fragments or masses of solid matter to form a compact whole [10]. Hydraulic calcium silicates are the primarily components of Portland cements which are hydraulic. Hydraulic cements react chemically with water to set and harden in a reaction called hydration. Cement and water combine to form a paste that resembles a stone and which acts as an adhesive and binds the aggregates together to form concrete. Where concrete is the world's most widely used and most versatile construction material [9].

Impact of Manufacturing Portland cement

The manufacturing process of Portland cement has a significant impact on the environment, energy consumption and the quality of the final product. Portland cement is manufactured by pulverizing clinker. The clinker consists mainly of hydraulic calcium silicates. In addition it contains some calcium aluminates, calcium alumino-ferrites and one or more forms of calcium sulfate (gypsum). The calcium, silica, alumina, and iron components in the materials required to make Portland cement must be in the proper proportions. A uniformly high quality of cement is ensured by a frequent chemical analyses of all materials are made during manufacture [9].

Between 95 and 97 percent of calcination is finalized in a pre-calciner kiln before the meal leaves the lowest stage cyclone which is the process of breaking down $CaCO_3$ into CaO and CO_2. Free lime (FL) which is the unreacted CaO levels in hot meals show that some of it reacts with silicate minerals in the calciner. This occurs especially when the calcareous raw material is not pure and each hot meal particle encompasses both CaO and silicates in intimate contact [10].

The processes that produce alite and belite in the kiln are affected by temperature and residence time. Clinker achieves a temperature of between 1350°C and 1450°C in the burning zone, resulting in a FL content of 1% to 2% [10]. Unfortunately, this process is energy-intensive and generates 0.613 ton of CO_2 emission per ton of clinker is produced [1].

Physical properties of cement

Cement specifications bounds both on its physical properties and often on its chemical composition. In interpreting the results of cement tests, understanding the significance of some of the physical properties is helpful. The properties of cement are limited by their specifications, which are based on the type of cement. Cement is continuously monitored and followed up for its chemistry and the following properties during manufacture [9].

a. Particle Size and Fineness

The "fineness" of cement refers to the total particle size distribution which affects heat released and hydration rate. Greater cement fineness which is lower particle size promotes strength development by increasing the rate at which cement hydrates. The effects of finenesson paste strength are most noticeable within the first seven days. Fineness is a measure of surface area of cement particles per unit mass indirectly which indicates that cements with finer particles have more surface area. The outcome of pulverizing clinker in a grinding mill is Portland cement, which is made up of individual angular particles of various sizes. Cement particles have an average particle size around 15 micrometers where approximately 95% of cement particles are smaller than 45 micrometers [9].

b. Setting Time

The aims of performing setting time are to determine the initial set and final set of paste. Initial set is the time that counts from the moment water is added till the paste ceases to be fluid whereas final set is the time needed for a paste to attain a certain degree of hardness. This test is performed to determine if a cement sets based on the time limits in cement specifications using either the Vicat apparatus or the Gillmore needle in ASTM C 191 or AASHTO and ASTM C 266 or AASHTO 154 respectively [9].

c. Specific Gravity (Density and Relative Density)

The mass of a unit volume of the particles or solids excluding air in between the particles is termed as the density of cement. It is expressed as mega grams per cubic meter. The cement density obtained using ASTM C 188 or AASHTO T 133 does not indicate the quality it has, rather its basic use is in calculations for mixture proportioning. It may be more advantageous to express the density as relative or specific gravity which is a dimensionless number obtained by dividing the cement density by density of water at 4°C (1.0 g/cm^3 or 1000 kg/m^3). Portland cement has particle density ranging from 3.10 to 3.25 with an average value of 3.15 Mg/m3 which is used in volumetric computations of concrete mix proportioning [9].

2.3 Hydration of Concrete

Hydration is a chemical reaction between cement and water leading in the binding quality of Portland cement. 90% or more of the weight of Portland cement is made from tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite compounds. These four compounds are present in each type of Portland cements in different proportions. Several others play important roles in the hydration process in addition to these major compounds. Most of the individual cement compounds can be recognized and their amounts determine when the kiln product that is ground to make Portland cement is observed under a microscope even though the smallest grains escape visual detection. Approximately 15 micrometers is the average diameter of a typical cement particle [9].

About 75% of the weights of Portland cement are the two calcium silicates that react with water to form calcium hydroxide and calcium silicate hydrate. Calcium silicate hydrate is by far the most important cementing in concrete which contains lime (CaO) and silicate (SiO_2) in 3 to 2 ratio. Engineering properties such as: Setting, hardening, strength and dimensional stability basically rely on calcium silicate hydrate. It also forms dense, bonded aggregations between other crystalline phases and the remaining un-hydrated cement grains, grains of sand to pieces of coarse aggregate cementing together in hardened cement paste. Its gross volume remains almost unchanged as concrete hardens, but pores filled with water and air that have no strength are contained in hardened concrete. The solid part of the paste has the strength which is mostly carried by the calcium silicate hydrate and crystalline compounds [9].

When cement comes into contact with water, it begins to hydrate. On the surface of each cement particle, a fibrous growth occurs, which gradually expands until it connects with the growth of other cement particles or clings to nearby items. This fibrous buildup causes stiffness, hardness, and strength progressively. Concrete stiffening is identified by a loss of workability that occurs within three hours after mixing, but is dependent on the cement composition and fineness, any admixtures used, mixture proportions, and temperature conditions where eventually the concrete sets and becomes hard [9].

2.4 Supplementary Cementitious Materials

Extending cement using Secondary Cementitious Materials (SCMs) like as silica fume, metakaolin and rice husk ash is one of the main success stories of the last 40 years in having

a role to replace or enhance the use of Portland cement. Certainly, the testing of newly discovers cementicious materials and the effects of mixing dominate modern cement research [10]. Up to 5% of additional materials such as slag, fly ash or limestone can now be contained in cements and still be called as Portland cement. By merging these ingredients in higher amounts, as many as 27 common cements can now be set as standard [10]

As part of the complete cementitious system, supplementary cementitious elements are added to concrete. Depending on the properties of the materials and the desired effect on concrete, SCMs may be used in addition or as partial replacement of Portland cement or blended cement in concrete. They can also be utilized to improve a specific concrete quality, such alkali-aggregate reactivity resistance. Test should be done to establish the optimum amount of using SCMs to determine if the material is indeed advancing the property and to regulate the correct dosage rate in avoiding an overdose or under dose which may be harmful or not achieve the desired effect. The supplementary cementitious materials react differently with different cements. Fly ash, slag, calcined clay, calcined shale, and silica fume were traditionally used independently in concrete. Due to improved access to these materials, concrete producers can now combine two or more of them to improve concrete properties [9].

2.4.1 Natural Pozzolanas

Pozzolanic materials are siliceous or siliceous and aluminous materials that have little or no cementitious value on their own. There are two types of pozzolanic materials. Natural pozzolanas such as: Clay and Shales, Opalinc Cherts, Diatomaceous Earth, Volcanic Tuffs and Pumicites and Artificial pozzolanas such as: Fly ash, Blast Furnace Slag, Silica Fume, Rice Husk ash, Metakaoline and Surkhi. Mineral admixtures like finely ground marble, quartz, granite powder are also used that neither exhibit the pozzolanic property nor the cementitious properties rather act as inert filler [11].

In finely divided form and in moisture presence, they react chemically with calcium hydroxide liberated on hydration to form compounds owning cementitious properties at conventional temperature. One of the byproducts of hydration is calcium hydroxide on hydration of tri-calcium silicate and di-calcium silicate. This compound is soluble in water and has no cementitious value where it may be leached out by the percolating water. The siliceous or aluminous chemical reacts with calcium hydroxide in finely split form to generate very stable cementitious compounds including calcium, silica, and water. The pozzolanic reaction can be represented as follows:

Pozzolan + Calcium Hydroxide + Water → C – S – H (Gel)

This reaction has a number of distinguishing characteristics, the first of which is its slowness, which is reflected in the heat of hydration and the rate at which strength develops. The consumption of Ca (OH)2 is involved in the reaction not the production where it improves the durability of cement paste by making the paste dense and impervious. Calcium hydroxide, a water soluble material is converted into insoluble cementitious material by the reaction of pozzolanic materials. In general, amorphous silicate responds faster than crystalline form. [11].

2.5 Municipal Solid Waste Incinerated Fly Ash

Municipal solid waste ash is a material which is the by-product produced from the combustion of municipal solid waste and can be used to replace cement and sand in the concrete partially. These Municipal Solids originated from many sources such as houses, hospitals, and industries. Incineration ash is one of the major by-products of the mass-burn industry [12][13].The incineration of municipal solid waste reduces the mass and volume of waste, and decreases the landfilling of solid waste. However, the increasing amount of incineration residues and tax for landfilling promote alternative applications for them [14][1]. So this incineration of Municipal solid wastes (MSWI) generates millions of tons of residues worldwide every year and these quantities are expected to raise in the near future [15][1].

During the MSWI incineration process, the incinerator generates two main types of ashes: MSWI bottom ash (BA) and MSWI fly ash (FA). The MSWI BA residue was from the bottom of the incinerator. In contrast, MSWI FA was collected from air pollution control devices [16].

2.5.1 Classification of Fly-Ash

There are two basic types of fly ash: Class F and Class C. Both types react in concrete in similar ways. Both Class F and Class C fly ashes undergo a "pozzolanic reaction" with the lime (calcium hydroxide) created by the hydration (chemical reaction) of cement and water, to create the same binder (calcium silicate hydrate) as cement. In addition, some Class C fly ashes may possess enough lime to be self-cementing, in addition to the pozzolanic reaction with lime from cement hydration [7].

2.5.2 Effect of Fly Ash in Concrete Properties

Pan et.al [17] Studied the Recycling of MSWI bottom and fly ash as raw materials for Portland cement. The results indicated that cement production can be a feasible alternative for MSWI ash management. It is also evident that the addition of either fly ash or bottom ash did not have any effect on the compressive strength of the clinker. The laboratory-produced cement meets the requirements for Type II Portland cement, except that the setting times are slightly longer, possibly due to the over-burnt condition of the sintering.

The research carried out by Samrawit [18] investigated the use of Municipal Solid Waste Incinerator Bottom Ash (MSWI) as partial replacement of cement and studied the properties of concrete. In this experiment cement was partially replaced with municipal solid waste bottom ash at different percentages. The experimental result showed that the workability of concrete decreased with an increase of percentage replacement of cement by Bottom ash. The obtained results of compressive, tensile and flexural strength show decrement with an increase of bottom ash. However, the replaced concrete samples possess a better water tightness performance than the controlled sample. Finally the researcher concluded that Solid waste bottom ash can be used to partially replace cement in a normal strength concrete.

In Joshi [19] research the effect on compressive strength of concrete by partial replacement of cement with 0%, 10%, 20% and 30% of fly ash for M20 grade of concrete was made. Test results indicated that workability and durability of concrete increases with increase in fly ash content. It has also been obtained that with increase in fly ash content, there is reduction in compressive strength of concrete. The optimum replacement of cement with fly ash is 30%.

Lin [20] carried out the effects of the incorporation of municipal solid waste incineration fly ash in cement pastes and mortars. The authors concluded that the C-S-H structure in cement pastes containing fly ash is very close to that of pure cement pastes and the MSWI fly ash increases mortar setting times. Incorporating MSWI fly ash in mortars, up to 15 % (with an optimum for 10 %) in relation to the cement mass, increases their strength after (7, 28, and 90) beyond 15 %, the fly ash causes a slight decrease in strength,

Cristina [21] Had examined that, The MSWI fly ash slag was found to be comprised mainly of SiO2 and CaO, which can be substituted for up to 20% of the cement content in mortar, without sacrificing the quality of the resultant concrete. Also X-ray diffraction analysis reveals that when the W/C/0.38 and the curing age/28 days, the crystal patterns in the mortar samples, prepared with different amounts of cement having been replaced by MSWI fly ash slag are similar.

Zhiliang et.al [22] had also investigated that, the possibility of using municipal solid waste incineration fly ash as a supplementary cementitious material to replace part of the clinker in cement. Test results indicated that the main elements in MSWI FA are calcium, silica, alumina and iron, a composition similar to that of the mineral admixture used in cement-based materials. However, large amounts of chloride and traces of heavy metals are also detected, which means the ashes must be pre-treated before use as SCMs.

A.Polettini et.al [23] studied the properties of Portland cement mixtures containing fly ashes (FA) collected from four different Italian municipal solid waste incineration (MSWI) plants. The FA composition, revealing enrichment in heavy metals, chlorides and sulphates, significantly altered the hydration behavior of Portland cement. Consequently, for some of the investigated FA the maximum allowable content for the mixtures to achieve appreciable mechanical strength was 20 wt.%. Even at low FA dosages the setting of cement was strongly delayed.

Nikolina [24] investigated the technical properties of mortars containing MSWIFA. The study concluded that Consistency is not affected by MSWIFA content, although the workability time is prolonged. Air entraining admixture efficiency is lowered, but the effect lasts longer. The initial setting time is prolonged, and the flexural and compressive strengths are decreased in early terms because of the zinc presence in MSWIFA. MSWIFA does not influence the water demand, volume stability of mortars, or microstructure of cement hydration products.

Sébastien et.al [25] studied the influence of 0, 5, 10, 15 and 20 percent replacement of cement with MSWI fly ash on the flow and setting times of the mortars. They concluded that flow time increased with the increase in ash content and incorporating ash in the mortars considerably increased the initial and final setting times. There was a dramatic increase in setting times when the ash content was increased from 10 to 15%. Also the characterization of MSWI fly ash shows the main oxide components of fly ash were SiO2, CaO and Al2O3. Additionally, the ash has high chlorine, sodium and potassium contents. In addition to the above research Goh et.al [26] investigated the properties of municipal fly ash (MFA) samples collected from an incineration plant in Singapore over a period of 12 months. Test results indicated that the major composition present in all MFA samples was calcium oxide. The compressive strength tests indicated that up to 10% by weight of the Portland cement could be replaced by MFA, providing equal or better strength than the control up to an age of 180 days. However, considerable strength reduction occurs at replacement levels beyond 15%. Furthermore based on the research they suggested that MFA shows potential as a blended cement material due to its strength contributing and non-toxic characteristics. However, MFA treatment may be required due to the high chlorine content and loss on ignition (LOI) of the ash samples.

2.5.3 Gap identification

Many studies have examined the use of MSWI fly ash as a partial replacement of cement in concrete. However, most of these studies use the fly ash without any treatment, despite recognizing that it contains harmful components like chlorine and sulfur. These elements can negatively affect the quality and durability of concrete. There is lack of research exploring the use of treated MSWI fly ash in concrete, and how treatment method might improve concrete performance and reduce issue related to these elements. This gap indicates a need for further investigation in to effective treatment techniques and their impact on the properties of concrete when MSWI fly ash is used as SCMs.

3 MATERIAL AND METHODS

Under this chapter, the types and properties of materials used, sample preparation methods, experimental procedures, and test setups employed in the study are briefly described. The testing and material properties were determined in accordance with ASTM standards and specifications to ensure reliability and accuracy of the result.

The preparation of materials, testes, and experimental procedures were conducted at Adiss Ababa institute of technology (AAiT) material laboratory.

3.1 Material

The materials used for this research include cement, fine aggregate, coarse aggregate, water and fly ash.

3.1.1 Cement

Commercially available Ordinary Portland Cement (OPC) from the local market was used in this study instead of Portland Pozzolana Cement (PPC) because it ensures that the effects of fly ash as a partial replacement of cement are studied independently without interference from other pozzolanic materials present in Portland Pozzolana Cement. It also allows for a clear understanding of how fly ash affects the properties of concrete when add to OPC.

The specific brand of cement utilized was Messebo Ordinary Portland Cement, with CEM 42.5 R grade. The physical properties of the cement were examined, and it was found to have a relative density of 3.15g/cm^3.

3.1.2 Aggregate

Aggregate is a general term, which includes a coarse and fine aggregate. At least three-quarter of concrete is occupied by aggregate. In this study, the aggregate was supplied from the same source to avoid any variations that might arise from using different sources. All relevant laboratory tests, including specific gravity, bulk density, and moisture content, were conducted to ensure the aggregate met the required specifications for concrete work. Prior to testing, the aggregate was washed to remove impurities like silt, organic material, and any other dust which reduces its quality. Besides that, after drying, the aggregate was stored in a plastic bag until mixing to preserve its moisture content.

3.1.2.1 Fine Aggregate

Fine aggregates used in concrete are small-size filler material that passes through a 4.75mm sieve and retains on sieve 0.07mm sieve ASTM C-125 [27]. For this study, the fine aggregate was collected from Legehar commercial construction material site. The physical properties of fine aggregate obtained from laboratory test results are summarized in Table 3.1 below.

Table 3. 1 Physical properties of Fine aggregate

No	Test description		Test result
1	Silt content		2.42
2	Moisture content		2.04
3	Absorption capacity		4.8
4	Finesse modulus		2.97
5	Unit weight		1514.29
6	Specific gravity	Bulk	2.33
		The bulk (SSD)	2.44
		apparent	2.62

Table 3. 2 The particle size distribution of fine aggregate

Sieve size (mm)	Weight retained(g)	Percent retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C 33 standard passing range (%)
4.75	10	2	2	98	95-100
2.36	38.8	7.8	9.8	90.2	80-100
1.18	98.7	19.7	29.5	70.5	55-85
0.6	192.2	38.4	67.9	32.1	25-60
0.3	111.2	22.2	90.2	9.8	5-30
0.15	38.1	7.6	97.8	2.2	0-10
Pan	11	2.2	100	0	0

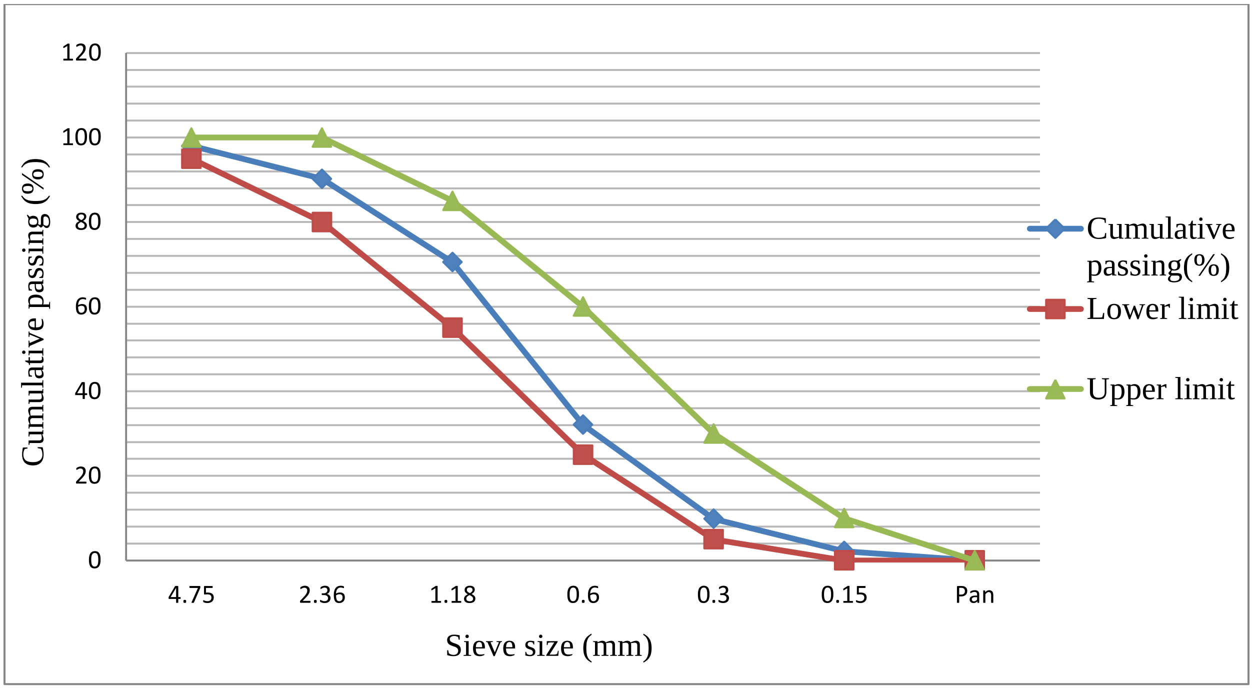

Figure 3. 1 Gradations of Local Fine Aggregate and ASTM C-33-01 Requirement

The fine aggregate was washed to minimize its silt content from 8.4% (original silt content) to 2.42%. According to ASTM C-33-01 [28], the upper and lower bound of percentage cumulative passing for fine aggregate in each sieve size is specified. The local fine aggregate used for this study satisfies ASTM C-33-01 [28] requirement.

3.1.2.2 Coarse aggregates

Basaltic crushed rock has been used as a coarse aggregate for this study which was obtained from a local material supplier. Coarse aggregates with 9.5-25mm were used. The following Table 3.3 and Figure 3.2 below show the physical properties obtained from the laboratory test results.

Table 3. 3 Physical properties of coarse aggregate

No	Test description		Test result
1	Moisture content		1.8
2	Absorption capacity		2.38
3	finesse modulus		2.37
4	Unit weight		1638.2
5	Specific gravity	Bulk	2.51
		The bulk (SSD)	2.6
		apparent	2.7

Table 3. 4 Particle size distribution of the coarse aggregate

Sieve size (mm)	Weight retained(gm)	Percent retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C 33 standard passing range (%)
37.5	0	0	0	100	100
25	245.4	4.9	4.9	95.1	90-100
19	1984.6	39.7	44.6	55.4	40-85
12.5	2086.7	41.7	86.3	13.7	10-40
9.5	561.7	11.2	97.6	2.4	0-15
4.75	119	2.4	99.9	0.1	0-5
pan	3.2	0.1	100	0	0

Figure 3.2 shows the local coarse aggregate gradation in adjacent the upper and lower boundaries according to ASTM-33-01**.**

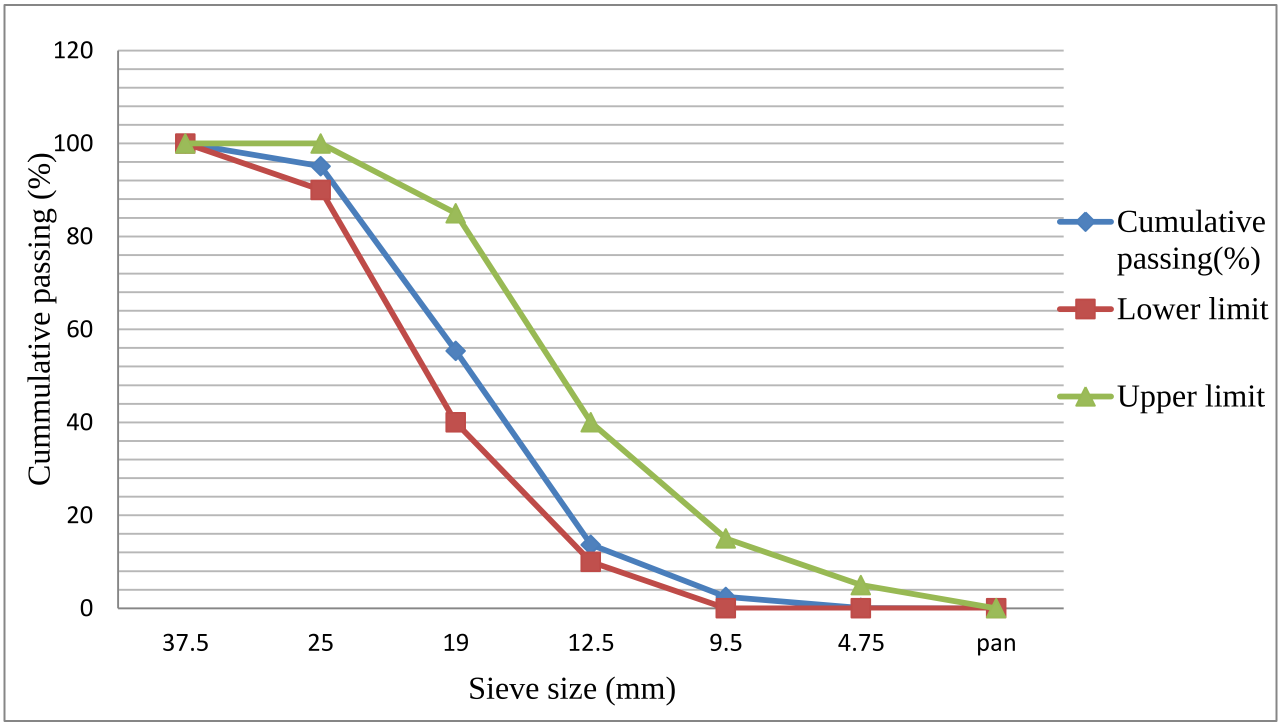

Figure 3. 2 Gradation of Local Coarse Aggregate and ASTM C-33-01 Requirement

3.1.3 Water

Water is an essential component of concrete as it strongly plays a part in the chemical reaction with cement. Moreover, to mix the concrete, the curing of concrete, washing of aggregate and for this study the treatment of fly ash also has been done by water. Therefore, water must not contain impurities such as alkalis, suspended solids, acids, silt, clay, and dissolved salt that cause degradation in quality like strength development, loss of workability, or steel corrosion in harmful quantities. Accordingly, the water used for this research is tap water from the construction material laboratory of Addis Ababa institute of Technology water supply pipe.

3.1.4 Fly Ash

The MSWI fly ash used in this study were obtained from the Reppi waste-to-energy power plant, located in koshe, Addis Ababa. Upon collection, the fly ash was used in both washed and unwashed forms.

Figure 3. 3 Reppi waste-to-energy power plant

1. Unwashed fly ash

The unwashed fly ashes were dried in an oven at 105^0c for 24 hours. It was then milling in to powder form using a crushing machine in the chemical laboratory and subsequently sieved through a 150 μm sieve before being utilized as Ordinary Portland Cement (OPC).

2. Washed fly ash

The washing of fly ash was performed to minimize impurities such as chlorine, sulfur, and other heavy metals.

Washing process

- Initially the ash was washed with water for 10minutes at a liquid-to-solid ratio of approximately 10:1.
- Next the ash was rinse with water.

- After washing, the ash was dried in an oven at 105°C for 24 hours, then milled and sieved, similar to unwashed fly ash, before being used as Ordinary Portland Cement (OPC).

According to the chemical test results in table 3.6, this washing process reduced the chlorine and sulfur content of the fly ash by 95.23% and 25.33%, respectively, demonstrating that water treatment is both effective and cost-efficient.

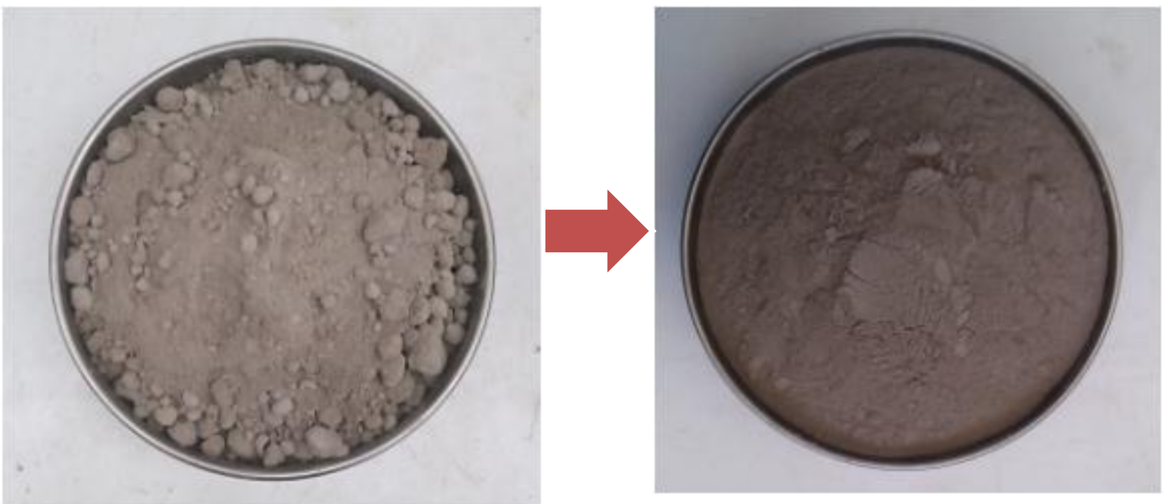

Figure 3. 4 Fly Ash before and after Sieving

3.1.4.1 Physical Properties

Specific Surface Area (Blaine Air-Permeability Test): The specific area of the fly ash is determined according to ASTM 2 204-00 [29] using Blaine air permeability apparatus. The specific surface area of washed and unwashed fly ashes was found to be reported in Table 3.5.

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Figure 3. 5 Blaine air permeability apparatus

Specific Gravity: The specific gravity of cement, washed and unwashed fly ash was examined. According to ASTM C127–88 [30] standard procedures the results were found to be listed in Table 3.5. The weight of fly ash used for volume-based replacement relays on its specific gravity.

Table 3. 5 physical properties of fly ash and cement

Fly ashes and cement	Physical properties	
	Specific gravity	Specific surface area(cm^2/g)
Washed FA	2.15	2326.18
Unwashed FA	2.36	2157.5
Cement	3.15	-

3.1.4.2 Chemical Properties

XRD Test

The potential applications of XRD power diffraction in the investigation of clinker and anhydrous cement include the quantitative and qualitative determination of phase composition, polymorphic modification, condition of crystallinity, and other individual phase properties.

In this study, the washed and unwashed ashes were brought to Addis Ababa University's chemistry department for an X-ray diffraction (XRD) test. It is determined the washed and unwashed FA crystalline and amorphous phases. The XRD data was examined using the Match software. Figure 3.4 and 3.5 depicts the XRD analysis results for the WFA and UNWFA samples respectively.

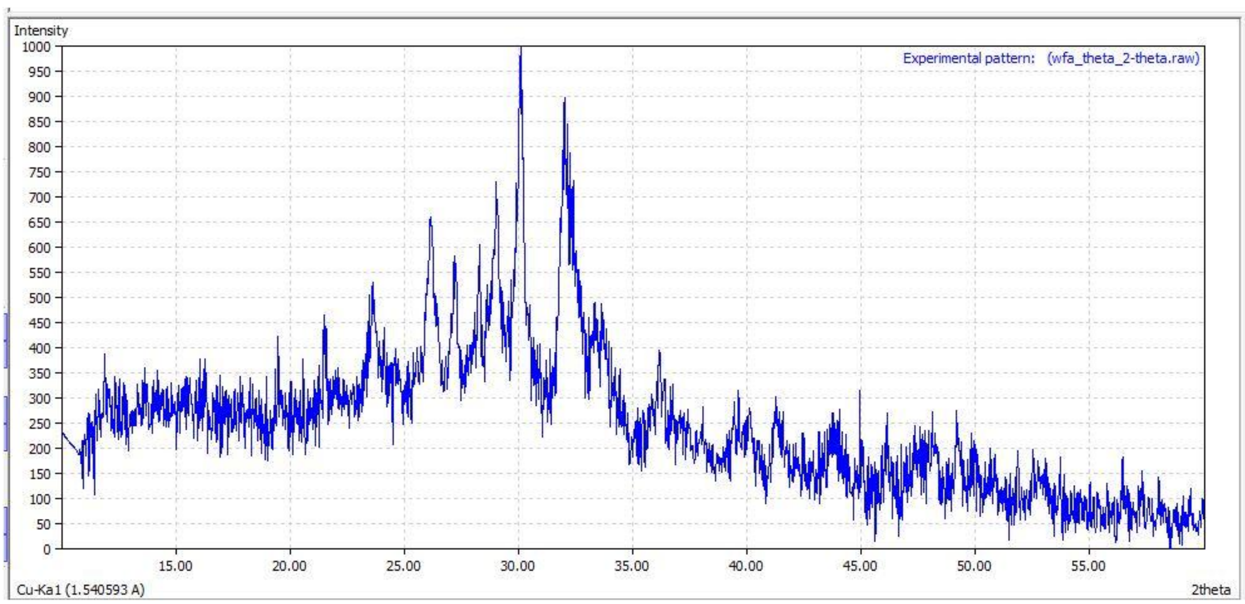

Figure 3. 6X-Ray Diffraction Result of WFA

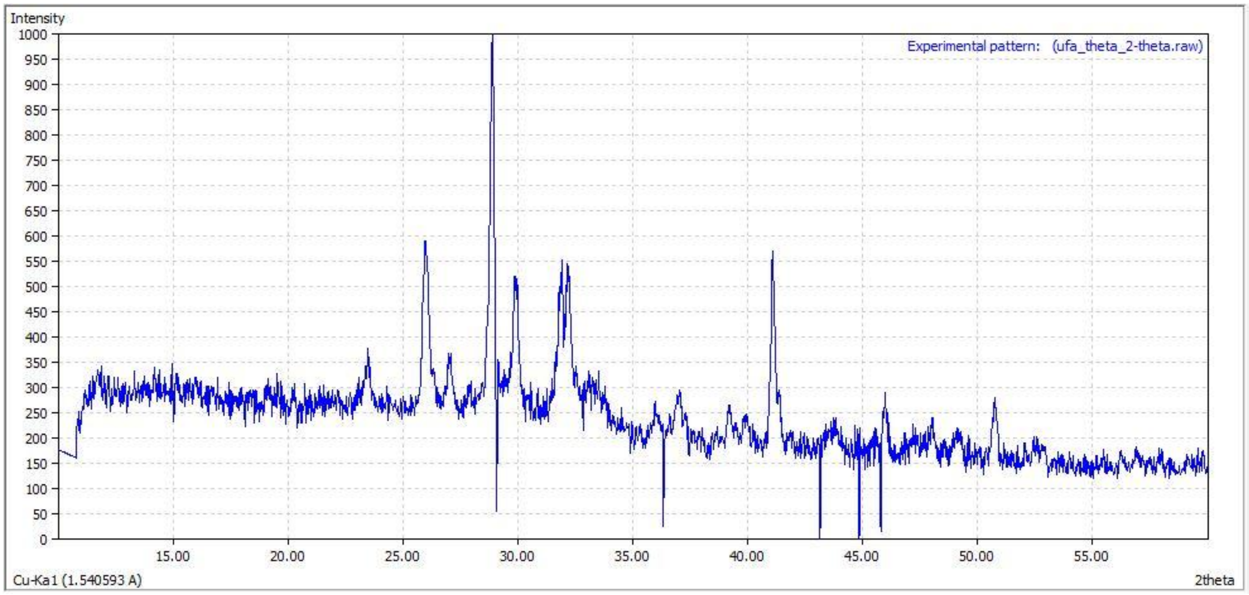

Figure 3. 7 X-Ray Diffraction Result of UNWFA

Referring to the XRD analysis, the sharp peak in Figure3.7 somehow transforms in to a hump in Figure 3.6. This hump indicates the amorphous phase, suggesting that after treatment, the washed fly ash contain a higher amount of the amorphous phase.

Complete Silica Analysis: The chemical property of washed and unwashed fly ash had been examined at Geological Institute of Ethiopian. The experiment result is reported in Table 3.6

Table 3. 6 Chemical Property of washed and unwashed fly Ash

compounds	unwashed fly ash	washed fly ash
SiO_2	19.02	25.42
Ai_2O_3	6.94	7.62
Fe_2O_3	3.92	5.78
CaO	20.5	32.2
MgO	3.66	4.5
Na_2O	3.68	1.86
K_2O	10.28	3.4
MnO	0.24	0.32
P_2O_5	2.14	2.62
TiO_2	0.96	1.24
H_2O	0.98	0.43
LOI	13.47	7.3<10
Cl^-	6.08	0.29

SO_3	7.7	5.75
SiO_{2+} Ai_2O_{3+} Fe_2O_3	29.88<50	38.82<50

The Silicate Analysis result in Table 3.6 shows the summation of oxides ($SiO_{2+}Ai_2O_{3+}Fe_2O_{3)}$ for washed and unwashed fly ash in the sample was found to be 38.82 and 29.88 respectively, which is less than 50 for both washed and unwashed fly ash. Since both washed and unwashed fly ash not satisfied the criteria in ASTM-C 618-00 [31] (standard specifications for coal fly ash and raw or calcined natural pozzolana). Also the chloride content in unwashed fly ash is 6.08%, which is something alarming because chloride is incompatible with reinforcement due to the risk of corrosion.

3.2 Methods

The methods applied in order to achieve the objectives are elaborated in this section. It includes mixture design and test setups for compressive strength, flexural strength and water penetration.

3.2.1 Mixture Design

The mixture design is accomplished using ACI 211.1-91 [32] standard procedure. Specified compressive strength of 25 MPa, Required average compressive strength, 33 MPa was pre-assigned for the control group. The quantity of each ingredient for the control group is summarized in Table 3.7.

Table 3. 7 Quantity of Material Required Per Metric Cube of Concrete

No	Material	Weight of material (kg/m^3)
1	Cement	386.77
2	Water	219.37
3	Coarse aggregate	1069.75
4	Fine aggregate	730.48

Using the above mixture proportion, a trial strength check had been carried out and confirmed the prescribed strength. In case of partial replacement of cement using washed and unwashed fly ash, volume-based replacement method was adopted. Volume based replacement is preferred in order to produce equal paste volume, that ensures justified comparison within all mixes.

According to ACI 211.1-91 [32] while using pozzolana material, Equation 3.1 can be used for determining the weight of pozzolana material as a function of the volume of replacement. The quantity of fly ash for each replacement level and the mix notation of concrete mixture are presented in Table 3.8 and Table 3.9 respectively for ease of reference.

$$Fw = \frac{1}{1 + (\frac{3.15}{Gp})(\frac{1}{Fv} - 1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. \quad \text{[Eq 3.1]}$$

Where: - Fw = Weight of pozzolana

Gp = Specific gravity of pozzolana

Fv = Percentage volume replacement level

Table 3. 8 Quantity of Fly Ash for Each Replacement Level

Mix notation	Weight of Fly ash (kg/m3)	Weight of Cement (kg/m3)	Water/Binder (Adjusted) By Volume
CO	0	386.77	0.567
WFA-10	27.288	348.093	0.584
WFA-15	41.612	328.755	0.592
WFA-20	56.421	309.416	0.6
UNWFA-10	29.676	348.093	0.581
UNWFA-15	45.097	328.755	0.587
UNWFA-20	60.927	309.416	0.592

Table 3. 9 Mix notation and expantion of notation

Mix notation	Expansion of notation
CM-0	Control mix with 100% OPC
WFA-10	Mixture with 10 % of washed fly ash and 90% OPC
WFA-15	Mixture with 15% of washed fly ash and 85% OPC
WFA-20	Mixture with 20% of washed fly ash and 80% OPC
UNWFA-10	Mixture with 10% of unwashed fly ash and 90% OPC
UNWFA-15	Mixture with 15% of unwashed fly ash and 85% OPC
UNWFA-20	Mixture with 20% of unwashed fly ash and 80% OPC

Table 3.8 shows that at the same replacement level, there is a variation in the weight of fly ash replacement between washed and unwashed fly ash, which is due to the slight difference in their

specific gravity. Since the weight of total binder decrease as an increase in fly ash replacement level, the water to binder ratio (in volume basis) will increase in some extent as shown in Table3.8.

3.2.2 Mixing, Vibrating, and Curing Condition

Mixing and curing concrete test specimens in the laboratory was carried out according to ASTM C192 [33]. All concretes were mixed in the laboratory using the mixer shown in Figure 3.8. The coarse aggregate was added to the mixer first followed by fine aggregate and cement, and then it was dry blended. Two- third of water was added and then the mixing was continued for additional minute. The remaining water is then added. The ingredients were thoroughly mixed in a mixer machine till uniform consistency was achieved. Mixing machine was lubricated with water in order to prevent it from absorbing mixing water.

Figure 3. 8 Mixing Machine and Ingredients ready for mix

Slump Test (Workability)

Slump tests of fresh concrete were done immediately after mixing to check the workability of concrete. The slump of every freshly mixed concrete is measured according to ASTM C-143 [34].

Figure 3. 9 Measuring Slump of Fresh Concrete

Fresh concrete was cast into a slump test cone were compacted per batch to determine its workability before being cast into the concrete cube molds. Before casting, machine oil was smeared on the inner surfaces of the molds. Finally, concrete was poured into the mold and compacted thoroughly and to ensure a proper consolidation, a table vibrator was used. After 24hrs the concrete specimens were taken out of their molds and put in a water tank for curing as shown in Figure 3.10 until the test date under normal air condition.

(a) **(b)**

Figure 3. 10 (a) Concrete Specimen after cast (b) Curing Concrete Specimens

3.2.3 Test Setup and Procedure

Concrete's mechanical properties can be examined using a variety of techniques. In this study, tests for compressive strength, and flexural based tensile strength were conducted. ASTM manual is adopted for clarifying the test setups and procedures.

3.2.3.1 Compressive Strength

Compressive strength provides a general indication of concrete quality. Compressive strength was determined using 15*15*15cm^3 cubical concrete cores at the laboratory. This test method consists of applying a compressive axial load at loading rate from 0.15-0.3MPa/sec to specimen until failure occur ASTM C-39 [35]. The universal compression testing machine used in this study is capable of determining both the failure load and stress.

Figure 3. 11 Compressive Strength Test Setup

3.2.3.2 Flexural Strength

A third-point load experiment has been adopted for determining the flexural capacity as specified in ASTM C78–00 [36]. The purpose of this test is to find out the concrete's tensile strength. It is sometimes referred to as rupture or bend strength.

Figure 3. 12 Flexural Strength Test Setup

3.2.3.3 Water penetration

To evaluate the water tightness of concrete made with washed and unwashed fly ash at different OPC substitution percentages, and to compare it with the controlled mix, a water penetration under pressure test was conducted. This test is crucial for ensuring durability, particularly in condition where concrete is exposed to water or moisture. For this test, concrete cube specimens measuring 15cm x 15cm x 15cm were cast. The test was carried out at curing period of 28 days.

After 24 hours of casting the concrete, the specimens were removed from the mold, and the surface that would be exposed to water pressure was roughened with a wire brush before being immersed in the curing tank. Care was taken to ensure that the water pressure was not applied to troweled surface of the specimen. Once the curing period was completed, the specimen was placed in the water apparatus for the penetration test, and a water pressure of 5 bar or 0.5 MPa was applied for 3 days (72 hour), with periodic observations made. The test was conducted according to (BS EN. 12390-8:2000) [37].

After the specified pressure application time, the specimen was removed from the apparatus, and the face exposed to the water pressure was wiped clean. Immediately after the specimen was placed in the compressive strength machine split in half perpendicular to the face that had been exposed to the water pressure. The splitting face was then dried to the level where the water penetration front was marked, and the average and maximum measured depth of penetration was recorded as a water penetration depth.

Figure 3. 13. Concrete sample water penetration test setup

4. RESULT AND DISCUSSION

This section presents the results from laboratory tests conducted to investigate the properties of both fresh and hardened concrete by partially replacing cement with washed and unwashed MSWI fly ash at various replacement levels. The samples were compared with both the control mixes and relevant standards to draw conclusions. The results from the slump test, compressive strength test, flexural strength test and water permeability test conducted on normal-strength concrete are discussed in this part of the research.

4.1 Fresh Concrete Properties

Slump test

To check the workability of fresh concretes, a slump test is performed. Slump tests conducted for each replacement level are presented below.

Table 4. 1 shows the results of the slump test.

Mix notation	Water/Binder (Adjusted) By Volume	Average slump Value(mm)
CO	0.567	68
WFA-10	0.584	45
WFA-15	0.592	38
WFA-20	0.6	30
UNWFA-10	0.581	50
UNWFA-15	0.587	30
UNWFA-20	0.592	27

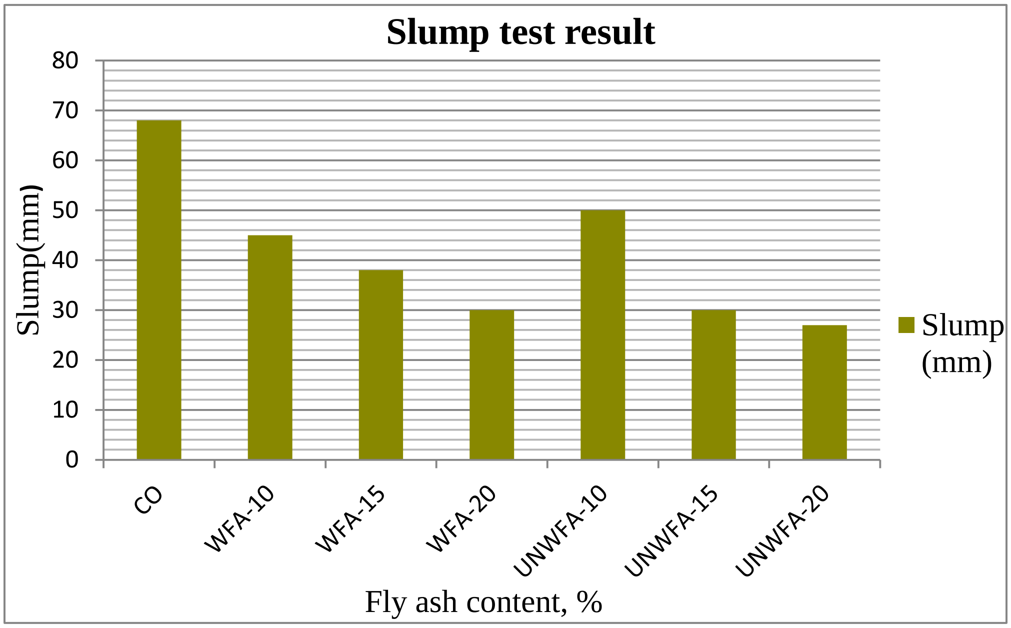

Figure 4. 1 The observed slump for concrete mix

As indicated in Table 4.1, the loss of workability was noticed with increasing the replacement level. Moreover, the immediate water absorption capacity is higher for the fly ash. The higher the finesse and the more irregular particle shape of SCM, the higher the water requirement for the concrete Ruben et al [38].

4.2 Hardened concrete properties

4.2.1 Compressive Strength

Experiments were conducted to study the compressive strength development of concrete at both early and later edges. These tests were performed at 3, 7, 28, 56 days for cement-fly ash replacement levels of 0%, 10%, 15%, and 20% using both washed and unwashed fly ashes separately. Due to the close values of the test results, two specimens were prepared for each mixture at each testing age, and the average compressive strength of the two samples was used as the result. The average results are reported in Table 4.2.

Table 4. 2 Average Compressive Strength

No	Mix notation	Average Compressive strength (MPa)			
		3 days	7 days	28 days	56 days
1	CO	18.16	23.14	34.61	44.67
2	WFA-10	17.57	22.43	34.66	39.84
3	WFA-15	17.36	22.74	35.71	40.72
4	WFA-20	18.57	24.06	29.82	36.54
5	UNWFA-10	19.19	22.87	37.89	44.22
6	UNWFA-15	18.65	23.79	37.99	43.59
7	UNWFA-20	22.36	28.74	32.07	39.14

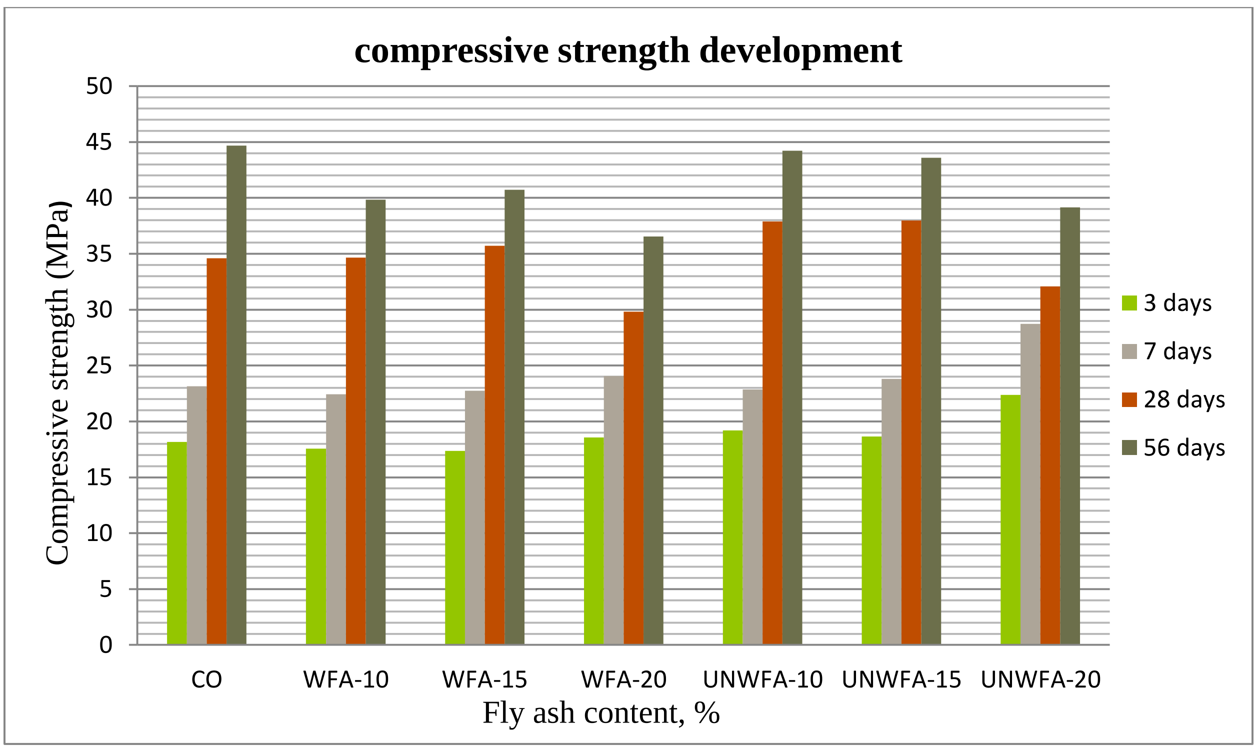

Figure 4. 2 Average Compressive Strength Development

From the result it can be seen that the average compressive strength value of concrete with unwashed fly ash showing relatively high strength value than the washed fly ash concrete samples in all replacement level. The Findings obtained in this study can be supported by

Olutoge and Amusan [39], who found an increase in the compressive strength of concrete for concrete specimen mixed and cured with sea water.

As shown in Table 4.2 the 3rd-day compressive strength of 10%, 15%, and 20% UNWFA replacements increased by 5.67%, 2.7%, and 23.13% respectively, and 56-day compressive strength of 10%, 15%, and 20% UNWFA replacements decreased by 1%, 2.4%, and 12.37% respectively, these result indicates presence of chlorine in concrete mix leads to slightly higher early strength but a lower long-term strength; the loss of strength usually not more than 15% and can be tolerated Neville [40]. Additionally chlorine In its inorganic form is non-toxic, but it destabilizes the passive film of steel rebar in reinforced concrete, resulting in rebar corrosion Mehta [41].

The 28th day compressive strength value of concrete with 10% and 15% washed fly ash replacement were showing a slight strength enhancement of about 0.15% and 3.78% respectively.

However, as replacement ratio increase to 20%, the compressive strength of both washed and unwashed fly ash concrete reduces from the reference. This is because ordinary Portland cement contains only about 20% Portlandite ($Ca(OH)_{2)}$, and at higher cement replacement levels with pozzolans, the strength development may be hampered due to a general lack of portlandite required for the pozzolanic reaction Yilmaz et.al [42].Overall, all the compressive strength results meet the minimum requirement of the characteristic compressive strength except 20% washed and unwashed fly ash replacements.

4.2.2 Flexural Strength

The flexural strength testes have been conducted at three, seven, twenty-eight and fifty-six days of curing for different replacement level of washed and unwashed fly ashes like that of the compressive strength testes.

Figure 4. 3 (a) Test Set up of flexural Strength Test (b) Test Specimen after Failure

Two samples were prepared for testing the flexural strength of a concrete in each percentage of replacement and at each day of investigation. The average flexural strength value of the concrete is summarized as shown in the table 4.3 below.

Table 4. 3 Average Flexural Strength

No	Mix notation	**Average Flexural Strength (Mpa)**			
		3 days	7 days	28 days	56 days
1	CO	2.86	3.5	4.05	4.52
2	WFA-10	1.97	3.06	3.54	3.63
3	WFA-15	2.19	2.57	3.89	4.03
4	WFA-20	2.23	2.5	3.11	3.18
5	UNWFA-10	2.15	2.52	3.12	3.27
6	UNWFA-15	2.24	2.78	2.96	3.25
7	UNWFA-20	2.33	2.79	2.98	3.13

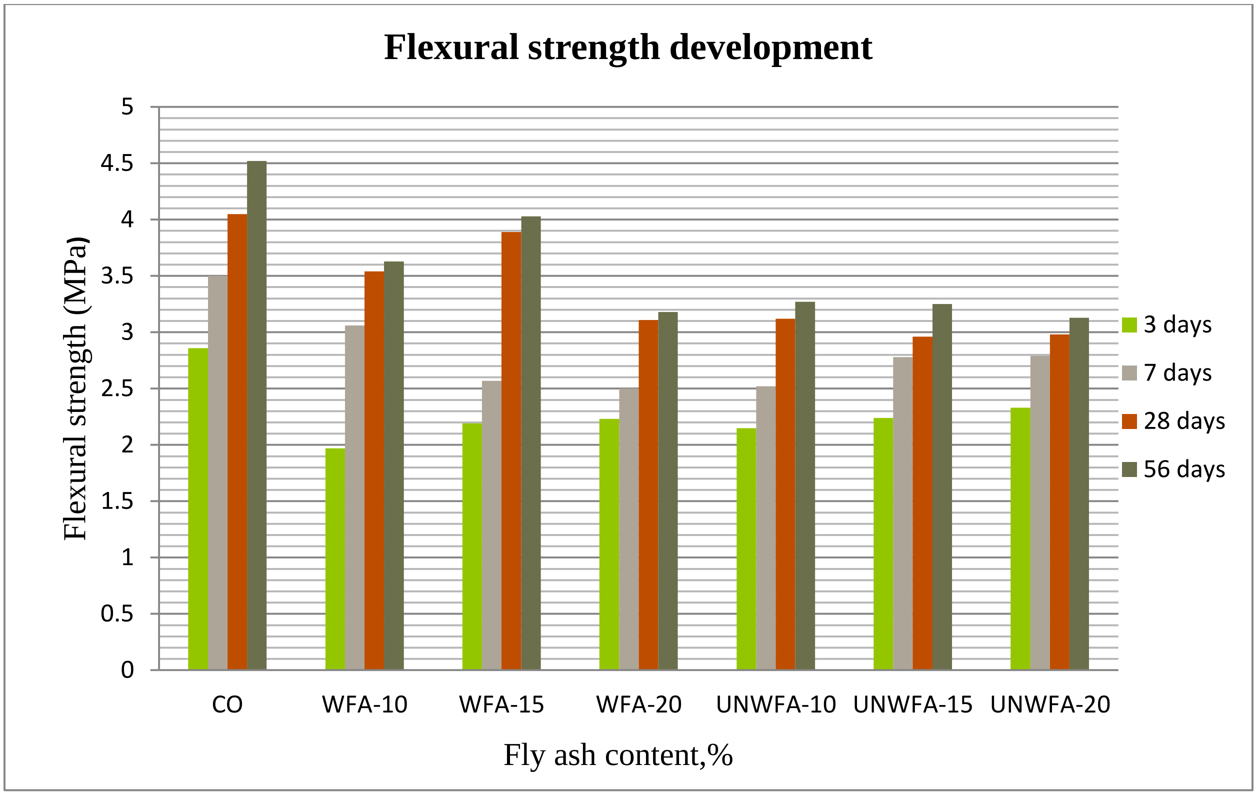

Figure 4. 4 Flexural Strength Development

During the test, most of the beams were falling by forming a crack which was occurring in the 1/3rd span of the beam and few were falling abruptly without showing noticeable warning.

It can be seen from the results that the replacement of cement by washed fly ash and unwashed fly ash reduce both early and late age flexural strength development. The 3rd-day flexural strength for mix WFA-10, WFA-15, WFA-20, UNWFA-10, UNWFA-15 and UNWFA-20 shows a reduction by 31.11%, 23.42%, 22.02%, 24.83%, 21.68% and 18.53% respectively, and The 28th-day flexural strength for mix WFA-10, WFA-15, WFA-20, UNWFA-10, UNWFA-15 and UNWFA-20 shows a reduction by 12.4%, 4%, 23.2%, 23%, 27% and 26.4% respectively, compared to the control mix**.** However 10% and 15% WFA replacement shows a better result. The flexural strength enhancement rate of WFA concrete is more during later ages (28 & 56) than early ages (3 & 7). The 28th day flexural strength of 15% WFA replacement gives almost the same result with the control.

4.2.3 Water Penetration

The water permeability results are shown in Table 4.4, the water penetration result at 28 days, with varying percentage of WFA and UNWFA replacement are displayed in Figure 4.5.

Table 4. 4 Average and maximum water penetration depth

Mix notation	Average water penetration depth (mm)	Maximum water penetration depth (mm)
CO	23.65	34.5
WFA-10	22.69	32.36
WFA-15	20.11	28.09
WFA-20	26.16	41.00
UNWFA-10	25.00	43.5
UNWFA-15	26.56	48.5
UNWFA-20	35.81	58.00

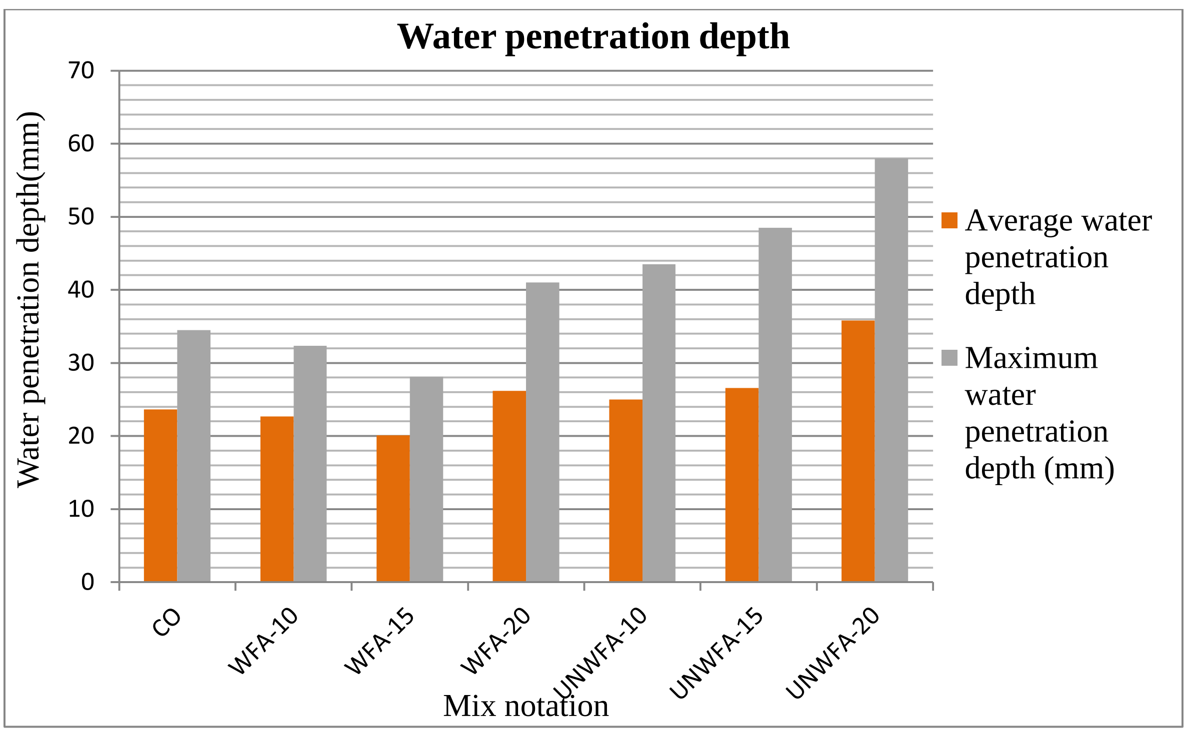

Figure 4. 5 Average and maximum water penetration depth

Figure 4. 6 concrete cube passing water penetration test when ready to be split (left) and after it was split (right).

After the split, the section of concrete where water had entered appeared darker than the portion of the concrete. The boundary between the darker section and the rest of concert was marked and measurements were taken.

Figure 4. 7 Concrete sample just after splitting

As shown in Table 4.4, the water penetration depth of concrete contains 10% and 15% washed fly ash shows relatively slower value than the control group and the unwashed fly ash replacements. On the other hand, replacing of cement by unwashed fly ash increase water penetration when increase the level of replacement. This finding is supported by Neville [40] who stated that, sea water (or any water containing large quantities of chloride) and use of seashore aggregates tends to cause persistent dampness and efflorescence. evaporation at the far surface of concrete leaves behind deposits of calcium carbonate, formed by reaction of $Ca(OH)_2$ with carbon dioxide; this deposit, of whitish appearance, is known as efflorescence. As efflorescence accumulates, it creates pores near the surface, increasing the permeability of concrete.

This suggests that treated fly ash play a significant role in enhancing the durability of the concrete.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study investigated the effects of using both untreated and water treated fly ash as partial replacements for cement in concrete. Based on the experimental investigation the following conclusions are drawn:

- The water demand for fly ash is found to be higher than cement, which can affect the workability of fresh concrete. This highlights the importance of adjusting the mix design when using fly ash to maintain desired consistency.
- The water treatment of fly ash resulted in a 95.3% reduction in chlorine and a 25.33% reduction in sulfur, indicating that water treatment is an effective method for improving the chemical quality of fly ash and reducing its negative impact on concrete performance and durability.
- From the result it can be seen that the average compressive strength value of concrete with unwashed fly ash showing relatively high strength value than the washed fly ash concrete samples in all replacement level.
- The 28th day compressive strength value of concrete with 10% and 15% washed fly ash replacement were showing a strength enhancement of about 0.15%and 3.78%respectively, from the reference mix.
- All substitution percentages had lower flexural strengths than the controlled sample for all curing periods; however the controlled sample's flexural strength is very close to those of the 10% and 15% substitutes of washed fly ashes.
- The water permeability of WFA-10 and WFA-15 was lower than that of the control group by 4.05% and 14.97%, respectively, indicating that the treatment has enhanced the durability of the fly ash up to 15 % WFA cement replacements.
- Overall, the findings of this study suggest that treated fly ash can be effectively used as partial replacement for cement up to 15%. It is not only contributes to sustainability by reducing cement consumption but also improve concrete performance in term of strength and durability when used at optimal levels.

5.2 Recommendations

5.2.1. Recommendations from This Study

- The findings highlight the potential of water treatment as an effective method for improving the quality of fly ash, particularly by reducing its chlorine content.
- This study suggests the treatment of MSWI fly ash with water and utilizing as a partial replacement for cement not only reduces the environmental impact of cement production but also contributes to sustainable construction practice.

5.2.2. Recommendations for Further Study

Based on this study, the following aspects are suggested for future study:

- Optimization studies on the use of MSWI fly ash as both cement and sand replacement material in concrete production.
- It is recommended to evaluate the performance of water treated MSWI fly ash as a cement replacement in high strength concrete.
- Investigation of long term properties such as shrinkage and creep play a critical role in the structural performance and durability of concrete.
- Future research should also include comprehensive life cycle assessments (LCA) and cost benefit analysis to quantify the environmental and economic advantage of using MSWI fly ash in concrete.

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APPENDIX

Appendix A - Tests for Fine Aggregate

A-1: Sieve analysis results of fine aggregate

Sieve size (mm)	Weight retained(g)	Percent retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C 33 standard passing range (%)
4.75	10	2	2	98	95-100
2.36	38.8	7.76	9.76	90.24	80-100
1.18	98.7	19.74	29.5	70.5	55-85
0.6	192.2	38.44	67.94	32.06	25-60
0.3	111.2	22.24	90.18	9.82	5-30
0.15	38.1	7.62	97.8	2.2	0-10
Pan	11	2.2	100	0	0

$$Fineness\ modulus = \frac{\sum(cumulative\ percent\ retained)}{100} = \frac{297.18}{100} = 2.97\%$$

A-2: Moisture content of fine aggregate

Weight of original sample (A) = 500g

Weight of oven-dry sample (B)=490g

$$\text{Moisture content(\%)} = \frac{(\text{A} - \text{B})}{\text{B}} * 100 = \frac{500 - 490}{490} * 100 = 2.04\%$$

A-3: Specific gravity for fine aggregate

Weight of original sample=500g

Weight of oven-dry sample (A) =477.1g

Weight of water+ weight of pycnometer (B) =706.7g

Weight of sample+ water+ pycnometer (C) =1001.9g

$$\text{Bulk specific gravity} = \frac{A}{B + 500 - C} = 2.33$$

$$\text{Bulk specific gravity (SSD basis)} = \frac{500}{B + 500 - C} = 2.44$$

$$\text{Apparent specific gravity } = \frac{A}{B + A - C} = 2.62$$

$$\text{Absorption capacity} = \frac{500 - A}{A} * 100 = 4.8\%$$

A-4: Silt Content

A = Amount of silt deposited above sand = 8mm

B = Amount of clean sand = 330mm

$\text{Silt content } \% = \frac{A}{B} * 100 = 2.42\%$

Appendix B - Tests for Coarse Aggregate

B-1: Sieve analysis results of coarse aggregate

Sieve size (mm)	Weight retained(g)	Percent retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C 33 standard passing range (%)
37.5	0	0	0	100	100
25	245.4	4.91	4.91	95.09	90-100
19	1984.6	39.69	44.6	55.4	40-85
12.5	2086.7	41.73	86.33	13.67	10-40
9.5	561.7	11.23	97.56	2.44	0-15
4.75	119	2.38	99.94	0.06	0-5
pan	3.2	0.06	100	0	0

$$Fineness\ modulus = \frac{\sum(cumulative\ percent\ retained)}{100} = \frac{237.19}{100} = 2.37\%$$

B-2: Moisture content of coarse aggregate

Weight of original sample (A) = 2000g

Weight of oven-dry sample (B)=1962.9g

$$\text{Moisture content(\%)} = \frac{(\text{A} - \text{B})}{\text{B}} * 100 = \frac{2000 - 1962.9}{1962.9} * 100 = 1.8\%$$

B-3: Specific gravity for coarse aggregate

Measurement oven dry sample in air (A) =1959.6g

Measurement in the air (SSD), Wt. of Sample (B) =2006.3g

Measurement in the water (SSD), Wt. of Sample (C) =1226.4g

$$\text{Bulk specific gravity} = \frac{A}{B - C} = 2.51$$

$$\text{Bulk specific gravity (SSD basis)} = \frac{B}{B - C} = 2.6$$

$$\text{Apparent specific gravity} = \frac{A}{A - C} = 2.7$$

$$\text{Absorption capacity} = \frac{B - A}{A} = 2.38\%$$

Appendix C - Mix Design

C-1: Mix Design for C-25

Step 1: - Material Data

NO	Test Description	Cement	Coarse Aggregate	Fine Aggregate
1	Specific Gravity	3.15	-	-
2	Bulk Density (Unit Weight)	-	1638.2kg/m^3	1514.29 kg/m^3
3	Moisture content:	-	1.8%	2.04%
4	Water absorption	-	2.38%	4.8%
5	Bulk Specific Gravity (SSD basis)	-	2.6g/cm3	2.44g/cm3
6	Silt content	-	-	2.42%
7	Fineness Modulus (FM)	-	2.37	2.97

Step 2: - Choice of Slump

According to ACI 211 Table: A1.5.3.1 the recommended slump To address more frequent constructions of concrete we considered Beams, Columns, and reinforced walls whose slump ranges between 25 to 100mm, maximum slump= 100mm, and minimum slump= 25mm.

Step 3: - Choice of Max size of Aggregate

Coarse aggregates =25mm

Step 4: - Estimation of Mixing water & Air content

Consider non-air-entrained concrete, from table 2 of ACI standards, for non-air entrained and slump of 75-100, the water in 1m^3 of concrete is 193 Kg.

Step 5: - Selection of Water-Cement ratio (W/C)

According to Table 6.3.4 (a) (Relationship between water-cement or water-cementitious materials ratio and 33 MPa compressive strength of concrete), for the slump of 75mm to 100mm, water to cement ratio is 0.499

Step 6: - Calculation of Cement content

Cement content (Kg) per cubic meter of concrete is: -$\frac{Water}{W/C} = \frac{193}{0.499} = 386.77kg/m^3$

Step 7: - Estimation of Coarse aggregate (CA) content

For FM = 2.97 of Fine aggregate and Maximum Size of aggregate

The volume of dry-rodded aggregate per cubic meter of concrete from the ACI Table is 0.653

Mass of Coarse aggregate, CA = Volume * Dry rodded unit mass= 0.653*1638.2= 1069.75kg /m^3

Step 8: - Estimation of fine aggregates content

Content of fine aggregate (F.A) = unit weight of concrete – (C.A + cement + water)

From table 5 the unit weight of fresh concrete corresponding to max. The aggregate size of 25mm and non-air entrained is 2380kg/m3.

Fine aggregate content = [2380 – (1069.75+386.77+193)] = 730.48kg/m3

Step 9: - Adjustment for aggregate moisture

If absorption capacity is greater than the moisture content of aggregate, we need to add water up to its moisture capacity.

C.A water = 2.38-1.8 = 0.58%

F.A water = 4.8 – 2.04 = 2.76%

Total water required = 193 + [1069.75 $*$ 0.58/100+ 730.48 $*$ 2.76/100 = 219.37Kg/m3

The estimated ingredients for a meter cube of concrete are, therefore, summarized as follows.

No	Material	Weight of materiala(kg/m^3)
1	Cement	386.77
2	Water	219.37
3	Coarse aggregate	1069.75
4	Fine aggregate	730.48

Appendix D - Test Results for Slump, Compressive strength and flexural strength

D-1: Test Results for Compressive Strength

Mix notation	Test Date	Weight (gm)	Failure Load (KN)	Compressive strength (MPa)	Average Compressive strength (MPa)
CO	3	8048	411.6	18.29	18.16
		8025	384.1	17.07	
		8118	430	19.11	
	7	8274	517	22.98	23.14
		7931	515.7	22.92	
		8218	529.3	23.53	
	28	8274	787.4	35	34.61
		8250	769.9	34.22	
	56	8377	994.8	44.21	44.67
		8499	1015.2	45.12	
WFA-10	3	8255	375.9	16.7	17.57
		8196	414.7	18.43	
	7	8303	499.9	22.22	22.43
		8243	509.3	22.64	
	28	8025	787.4	34.99	34.66
		8039	772.4	34.33	
	56	8211	883.4	39.26	39.84
		8028	909.4	40.42	
WFA-15	3	8008	377.5	16.78	17.36
		7221	403.7	17.94	
	7	8186	506.2	22.49	22.74
		8252	517.4	22.99	
	28	8163	783.2	34.81	35.71
		7994	823.6	36.61	
	56	8081	924.7	41	40.72
		8032	909.6	40.43	
WFA-20	3	7876	409.4	18.02	18.57
		7975	430	19.11	
	7	8136	541.1	24.05	24.06
		8153	541.5	24.07	
	28	8159	682.1	30.31	29.82
		7988	659.6	29.32	
	56	8002	848.9	37.73	36.54
		8035	795.5	35.35	
UNWFA-10	3	8101	458.8	20.39	19.19
		8108	404.7	17.99	
	7	8280	518.4	23.04	22.87

		8188	510.4	22.69	
	28	7992	884.4	39.31	37.89
		8093	820.8	36.47	
	56	8310	1032	45.87	44.22
		7934	957.6	42.56	
UNWFA-15	3	7972	412.9	18.35	18.65
		7854	426.2	18.94	
	7	7994	541.1	24.05	23.79
		8093	529.3	23.53	
	28	8107	837	37.2	37.99
		7904	872.3	38.77	
	56	7969	993.3	44.15	43.59
		7941	967.9	43.02	
UNWFA-20	3	7878	506.4	22.51	22.36
		7902	499.5	22.2	
	7	8131	651.1	28.94	28.74
		8090	642.1	28.54	
	28	8006	727.2	32.28	32.07
		8053	716.9	31.86	
	56	8273	883.2	39.25	39.14
		7952	887.9	39.02	

D-2: Test Results for Flexural Strength

Mix notation	Test Date	Weight (gm)	Failure Load (KN)	Flexural strength (MPa)	Average Flexural strength (MPa)
CO	3	11922	7	3.16	2.86
		13098	5.7	2.55	
	7	13037	7.4	3.32	3.5
		13099	8.2	3.67	
	28	13926	8.9	4.03	4.05
		13602	9.1	4.07	
	56	13320	10.3	4.65	4.52
		13573	9.8	4.39	
WFA-10	3	13041	4.6	1.9	1.97
		11917	4.7	2.03	
	7	12929	6.4	2.88	3.06
		12867	7.2	3.24	
	28	13029	8.2	3.66	3.54
		13004	7.6	3.41	
	56	11989	8.3	3.75	3.63
		13573	7.8	3.51	

WFA-15	3	13113	5.4	2.23	2.19
		13010	4.9	2.14	
	7	13134	6.2	2.73	2.57
		11875	5.4	2.41	
	28	13144	8.7	3.92	3.89
		13148	8.6	3.86	
	56	12859	8.9	4.01	4.03
		13386	9	4.05	
WFA-20	3	11751	4.2	1.73	2.23
		13271	6	2.72	
	7	11830	5.1	2.24	2.5
		11915	6.2	2.75	
	28	13128	6.9	3.1	3.11
		13392	6.9	3.11	
	56	12983	7.1	3.13	3.18
		12029	7.2	3.23	
UNWFA-10	3	13172	4	1.8	2.15
		13419	5.5	2.49	
	7	13154	5.7	2.52	2.52
		13308	5.6	2.51	
	28	13148	7	3.13	3.12
		13069	6.9	3.11	
	56	11993	7	3.14	3.27
		11669	7.6	3.4	
UNWFA-15	3	12754	4.4	1.96	2.24
		12627	5.6	2.51	
	7	12545	6.3	2.85	2.78
		12279	5.9	2.7	
	28	12827	6.4	2.89	2.96
		13277	6.8	3.03	
	56	11932	7.4	3.32	3.25
		12018	7.1	3.17	
UNWFA-20	3	12784	6.3	2.84	2.33
		11759	4.1	1.81	
	7	12725	6.1	2.73	2.79
		12183	6.3	2.85	
	28	13313	6.8	3.05	2.98
		13101	6.6	2.9	
	56	11914	6.9	3.11	3.13
		11844	7	3.15	

D-3: Slump Test Results

Mix notation	Slump Value(mm)	Average Slump Value(mm)
CO	69	68
	67	
WFA-10	44	45
	46	
WFA-15	36.5	38
	39.5	
WFA-20	29	30
	31	
UNWFA-10	49	50
	51	
UNWFA-15	30	30
	30	
UNWFA-20	28	27
	26	

Appendix E - Chemical property of washed and unwashed 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;Merem Sualih

Issue Date:-18/11/2024
Request No:- GLD/RQ/388B/24
Report No:- GLD/RN/4016/24
Number of Sample:One(01)

Sample type; unwashed FA
Sample Preparation:-200 Mesh
Date Submitted ;16/10/2024
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	Cl^-	SO_3	weight of sample
unwashed FA	19.02	6.94	3.92	20.50	3.66	3.68	10.28	0.24	2.14	0.96	0.98	13.47	6.08	7.70	1kg

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

- LOI = Loss on Ignition

Analysts	Checked By	Approved By	Quality Control
Haimanot Bayeh	Nigist Fikadu	Lidet Endeshaw	Aleminesh Abate
Kindie Kasahun			
Melkamu Debalkie			
Shashe Haile			

Geochemical Laboratory Desk Page 1

	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;Merem Sualih

Issue Date:-18/11/2024
Request No:- GLD/RQ/388A/24
Report No:- GLD/RN/4016/24
Number of Sample:One(01)

Sample type; washed FA
Sample Preparation:-200 Mesh
Date Submitted ;16/10/2024
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	Cl^-	SO_3	weight of sample
Washed FA	25.42	7.62	5.78	32.20	4.50	1.86	3.40	0.32	2.62	1.24	0.43	7.30	0.29	5.75	350gm

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

- LOI = Loss on Ignition

N

Analysts	Checked By	Approved By	Quality Control
Haimanot Bayeh	Nigist Fikadu	Lidet Endeshaw	Aleminesh Abate
Kindie Kasahun			
Melkamu Debalkie			
Shashe Haile			

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