INVESTIGATION ON PROPERTIES OF GREEN CONCRETE WITH FLY ASH AS CEMENT REPLACEMENT

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This report is submitted in fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering

Faculty of Mechanical Technology and Engineering

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APPROVAL

I hereby declare that I have read this project report and, in my opinion, this report sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Honours.

Signature : ....

Supervisor's Name : DR. MIZAH BINTI RAMLI

Date : Jan 2025

DECLARATION

I hereby declare that this project report entitled “Investigation on Properties of Green Concrete with Fly Ash as Cement Replacement” is the result of my own work except as cited in the references.

Signature :

Name : EAZWAN SYAFIQ BIN CHE AZID

Date : Jan 2025

DEDICATION

To my parents, family and supervisors, who have served as my beacon of light during this adventure. Your constant encouragement, insight, and support have given me the willpower to keep going. "Before you start anything, make sure you have the view of how you're going to end it," as my father, Che Azid Nor, used to say. That belief, as well as all the support and affection I have gotten along the journey, are all reflected in this work.

ABSTRACT

This study attempts to give an insight into the performance of concrete prepared with varying percentages of Fly Ash and additives in terms of compressive strength, water absorption, density, and microstructure. This concrete was produced in two batches: Batch 1 where, at replacement percentages of FA at 10%, 20%, and 50%, concrete was prepared, whereas for Batch 2, concrete was prepared, following the same replacement percentages, but this time incorporating additives such as calcium chloride ($CaCl_2$) and a superplasticizer. Experimental testing was carried out based on international standards to ascertain the mechanical properties, hydration behavior, and durability. It was observed that an increase in the FA content caused a decrease in compressive strength and density. Compressive strength was reported to be 11.5 MPa in a mixture where 10% was replaced by Fly Ash. Workability improved by the addition of additives but decreased compressive strength. By microstructural analysis, it was indicated that the gel of C-S-H was found to have a dense structure in low Fly Ash levels. However, Fly Ash higher contents are associated with higher porosity and undissolved particles. Water absorption was slightly higher for mixes with additives: 5.23-9.06%, proving their modified pore structures. EDX and FE-SEM analysis supported the same findings about how Fly Ash and additives were affecting hydration and durability. The paper, therefore, emphasizes how optimization of Fly Ash replacement and additive dosages can result in the development of sustainable concrete with improved performance.

ABSTRAK

Kajian ini cuba memberi gambaran tentang prestasi konkrit yang disediakan dengan pelbagai peratusan FA dan bahan tambahan dari segi kekuatan mampatan, penyerapan air, ketumpatan, dan struktur mikro. Konkrit ini dihasilkan dalam dua kelompok: Batch 1 di mana, pada peratusan penggantian FA pada 10%, 20%, dan 50%, konkrit telah disediakan; manakala untuk Batch 2, konkrit telah disediakan, mengikut peratusan penggantian yang sama, tetapi kali ini menggabungkan bahan tambahan seperti kalsium klorida ($CaCl_2$) dan superplasticizer. Ujian eksperimen telah dijalankan berdasarkan piawaian antarabangsa untuk memastikan sifat mekanikal, tingkah laku penghidratan dan ketahanan. Telah diperhatikan bahawa peningkatan dalam kandungan FA menyebabkan penurunan kekuatan mampatan dan ketumpatan. Kekuatan mampatan dilaporkan ialah 11.5 MPa dalam campuran di mana 10% digantikan oleh FA. Kebolehkerjaan dipertingkatkan dengan penambahan bahan tambahan tetapi mengurangkan kekuatan mampatan. Dengan analisis mikrostruktur, ia menunjukkan bahawa gel C-S-H didapati mempunyai struktur padat dalam tahap FA yang rendah; walau bagaimanapun, kandungan FA yang lebih tinggi dikaitkan dengan keliangan yang lebih tinggi dan zarah tidak terlarut. Penyerapan air adalah lebih tinggi sedikit untuk campuran dengan bahan tambahan: 5.23-9.06%, membuktikan struktur liang yang diubah suai. Analisis EDX dan FE-SEM menyokong penemuan yang sama tentang cara FA dan bahan tambahan mempengaruhi penghidratan dan ketahanan. Makalah itu, oleh itu, menekankan bagaimana pengoptimuman penggantian FA dan dos tambahan boleh menghasilkan pembangunan konkrit lestari dengan prestasi yang lebih baik.

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Alhamdulillah and thanks to God with all the bounty and grace that has been given to me to complete this study as required by Universiti Teknikal Malaysia Melaka, UTeM.

Special thanks to Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for providing me with a very helpful supervisors for my study, Dr. Mizah binti Ramli. I would like to thank Ts. Dr. Nurul Hanim Binti Razak for her support during completing this research. Lastly, thank you to everyone who has been to the crucial parts-directly or indirectly in my study period.

I dedicated this report to all those respectful beings who have helped me in any way to become what I am today. Those sacrifices seeded my success, especially my parents, Che Azid bin Hj. Nor and Wan Senah binti Abdullah who have felt my pain beyond me and never-ending prayers and support. My family, who understand the struggle we all suffered. I consider them a divine source of encouragement.

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LIST OF ABBREVIATIONS

- SDG: Sustainable Development Goals
- FA: Fly Ash
- BA: Bottom Ash
- WHO: World Health Organization
- MWIFA: Medical Waste Incineration Fly Ash
- MSWIFA: Municipal Solid Waste Incineration Fly Ash
- FE-SEM: Field Emission Scanning Electron Microscope
- %: Percentage
- Zn: Zinc
- Ch: Chromium
- Pb: Plumbum/Lead
- Cd: Cadmium
- Hg: Mercury
- PVC: Polyvinyl Chloride
- PET: Polyethylene Terephthalate
- PP: Polypropylene
- APCD: Air Pollution Control Device
- PCC: Portland Cement Concrete
- wt: Weight
- at: Atomic
- ASR: Alkali Silica Reaction
- GGBS: Ground Granulated Blast-furnace Slag

CHAPTER 1

INTRODUCTION

1.1 Background

United Nations General Assembly in 2015 adopted the Sustainable Development Goals (SDGs). It includes a powerful framework for international cooperation to achieve sustainability. It has 17 SDG goals and 169 targets to be achieved before 2030. It is also a universal call to action to end extreme poverty, fight inequality, and injustice and protect the planet and the environment (Gielen, et al., 2019).

Few causes of pollution have been determined to save our planet and the environment. Malaysia is a country that is fast expanding in every industry area. Examples are the agriculture industry, manufacturing industry, automobile industry, and others. Meanwhile, the construction industry is one of the sectors that significantly contributes to the country's infrastructure and facilities development.

However, neglecting sustainability and environmental effect will not help the construction sector to be more successful (Bin Abd. Ghani & Ahmad Zawawi, n.d.) In the construction sector, project development increasing with demand for building materials, especially concrete. In terms of consumption, it be the second most consume material after water.

Producing concrete consume large number of raw materials and leads to negative impact to environment (Opon, and Henry, 2019). Concrete consists of few materials such as cement, fine aggregates and coarse aggregates. As the demand of concrete increasing, large supplies needed to be harvest from the environment. One of the materials used is sand that can be mined from lakes, riverbeds or coastlines.

According to the United Nations Environment Programme, sand is the most mined materials with some of 50 billion are extracted each year (Hernandez et. al, 2021). This can lead to excessive quantity while affecting the environment. The effect might be reduction of water quality and destabilization of stream bed. Concrete is like an artificial stone-like mass. It is a composite material that is made by proportionally combining aggregate.

In simpler form, concrete is a combination of paste (Portland cement and water) and particles (sand, gravel, and aggregates). To reduce the environmental effect of making concrete, mixing the fine aggregates with waste such as clinical waste has been proposed. CFA can be added as supplementary cementitious material to produce a block of concrete suspecting having better strength and mechanical properties than regular concrete. Clinical waste or biomedical waste is produced in large quantities by hospitals, medicals, and research facilities.

Yi,2023 claimed that clinical waste generation in Malaysia was reported up to 33,000 tonnes per year. Table 1 shows the common categories of clinical waste (Tiwari & Kadu, 2013). Therefore, the best way to reduce waste and eliminate potentially harmful microorganisms is by incineration process. Waste is burned into residual ash, bottom ash (BA), and smoke or fly ash (FA) during the high thermal heat oxidation process. The fly ash then can be used to mix it with cement to build concrete.

Table 1: Common Categories of Clinical Waste

CATEGORY	WASTE RESOURCES	COMPONENTS
CATEGORY 1	Human Anatomical Waste	**HUMAN TISSUES, ORGANS, AND BODY PARTS**
CATEGORY 2	Animal Waste	**ANIMAL TISSUES, ORGANS, BODY PARTS, BLOOD**
CATEGORY 3	Microbiology and Biotechnology Waste	**FROM LABORATORY CULTURES, STOCKS, OR SPECIMEN**
CATEGORY 4	Waste Sharps	**NEEDLES, SYRINGES, SCALPELS, BLADES, GLASSES**
CATEGORY 5	Discarded Medicines	**WASTE CONSISTS OF OUTDATED, CONTAMINATED MEDICINES**
CATEGORY 6	Solid Waste	**ITEMS CONTAMINATED WITH BLOOD, BODY FLUIDS**
CATEGORY 7	Solid Waste	**CATHETERS, INTRAVENOUS, ETC.**
CATEGORY 8	Liquid Waste	**GENERATED FROM THE LABORATORY AND WASHING, CLEANING**
CATEGORY 9	Incinerated Ash	**ASH FROM INCINERATIONS OF ANY BIO-MEDICAL WASTE**
CATEGORY 10	**CHEMICAL WASTE**	**CHEMICALS USED IN THE PRODUCTION OF BIOLOGICAL, CHEMICAL**

1.2 Problem Statement

In recent years, Malaysia has been grappling with the growing challenge of managing clinical waste, which has surged due to the expansion of healthcare services and increased public health demands. The country generates approximately 40,000 metric tonnes of clinical waste annually, with each hospital bed contributing between 0.3 and 0.8 kg of waste daily (Ng, 2020). The primary method of disposal is incineration, a process that produces by-products such as fly ash (FA) and bottom ash (BA). While FA is often recycled into solid fuel for further combustion, BA, the non-combustible residue, is generally disposed of or used in limited applications, such as in construction materials.

The reliance on incineration poses significant environmental and health concerns. Fly ash and bottom ash contain hazardous materials, including heavy metals and toxic compounds, that can leach into the environment if not managed properly. This not only contributes to air and soil pollution but also presents long-term risks to public health and ecosystems. Despite efforts to recycle these by-products, the utilization rate remains low, leaving a substantial amount of ash unutilized and contributing to the waste problem.

In addition to environmental concerns, the economic burden of clinical waste management is becoming increasingly unsustainable. The cost of disposing of clinical waste, which includes transportation and treatment, has risen sharply, from RM5.20 per kilogram (Razali & Ishak, 2010) to RM7.00 per kilogram in recent years. This escalating cost places a strain on healthcare budgets, particularly in government hospitals and public health institutions, which are already under pressure to deliver affordable care.

Moreover, the growing volume of clinical waste highlights inefficiencies in current waste management practices, such as limited recycling initiatives and inadequate exploration of alternative disposal or reuse methods. Despite its potential, the use of bottom ash in construction applications remains underutilized, with concerns about its long-term safety and performance acting as barriers to wider adoption.

These challenges underscore the urgent need for innovative, sustainable, and cost-effective solutions to manage clinical waste and its by-products. Addressing these issues is essential to minimize environmental pollution, reduce disposal costs, and promote the circular economy by repurposing waste materials for beneficial uses.

As for the solution, it is good that supplementary material from the fly ash will reduce environmental impacts. It will also help in recycling and reducing the cost of waste disposal in the form of fly ash or bottom ash. To confirm its suitability, a few tests need to be done such as physical, mechanical, the curing condition and its morphology.

Figure 1: Clinical Fly Ash

1.3 Objectives

The objectives of this project are to keep it on track and properly established. The key goals of this project are as follows:

- To study the physical properties and curing condition of fly ash reinforced concrete mixture.
- To analyse the mechanical behaviour and surface morphology of fly ash reinforced concrete.

1.4 Scopes of Study

Table 2 shows the research questions, objectives of research and the scopes of research. As for limitations, the usage of additives may have implications on the concrete mix so more thorough study need to be done.

Table 2: Research Questions, Objectives of Research and Scopes of Research

RESEARCH QUESTION	OBJECTIVES OF RESEARCH	SCOPE OF RESEARCH
WHAT ARE THE POTENTIAL APPLICATIONS OF CLINICAL WASTE FLY ASH IN CONSTRUCTION MATERIALS?	To study the physical properties and curing condition of fly ash reinforced concrete mixture	Conduct laboratory experiments to analyse the performance of concrete incorporating clinical fly ash
HOW DOES THE INCORPORATION OF CLINICAL FLY ASH AFFECT THE PROPERTIES AND PERFORMANCE OF CONCRETE?	To analyse the mechanical behaviour and surface morphology of fly ash reinforced concrete	Investigate the feasibility and performance of clinical fly ash in alternative applications beyond traditional construction materials

1.5 General Methodology

Figure 2 exhibits clear and detailed pictures of the general methodology we used throughout this project. This visual guide walks you through each step of our process, showing how we systematically worked toward our goals. The methodology covers several phases, starting with initial planning and data collection, moving through analysis and implementation, and ending with evaluation. By following this organized approach, we aimed to achieve accuracy, efficiency, and positive outcomes.

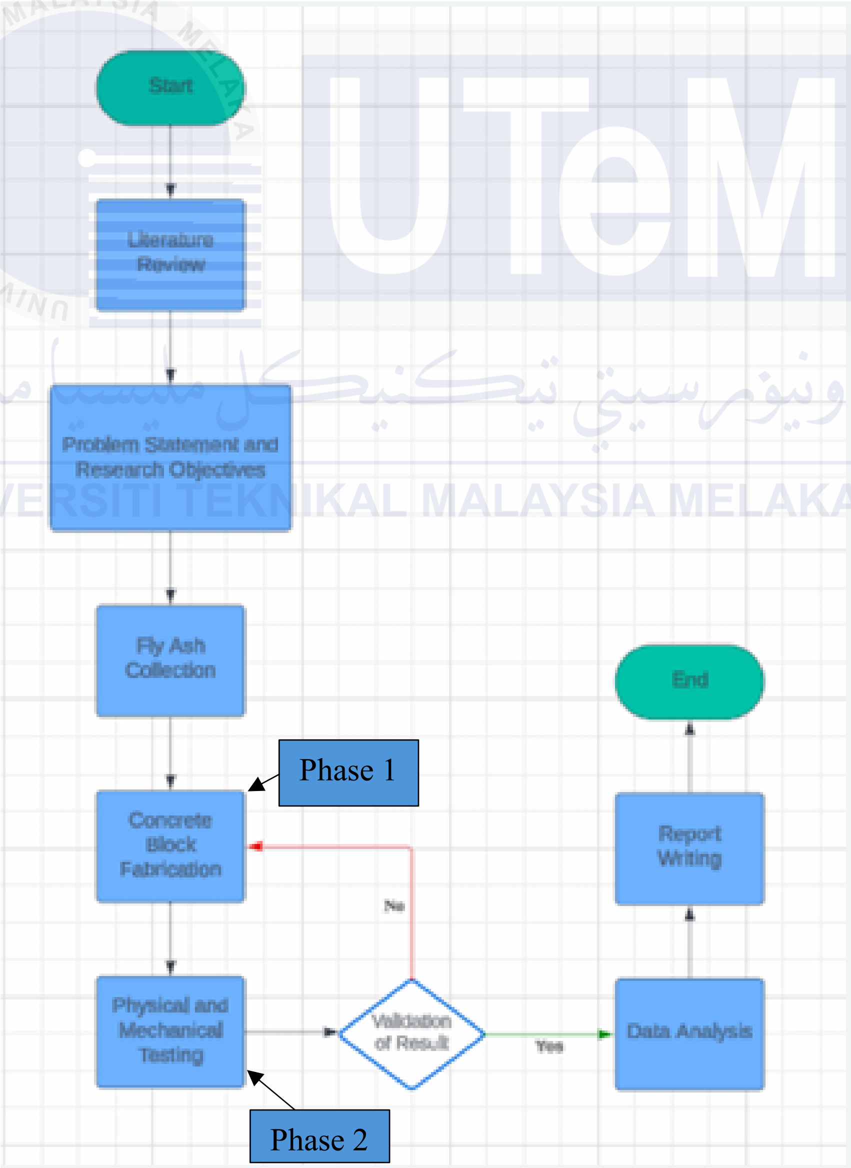

Figure 2: General Methodology

Phase 1: Concrete Fabrication

1. Design the composition of materials to be used in concrete.
2. Weight the materials according to each specification, different ration of FA to cement are used.
3. Mix all the materials to form a uniform concrete mix, by using a concrete mixer.
4. Perform slump test to measure the flowability of the concrete.
5. Place the concrete into moulds.
6. Cure the concrete for 28 days.

Phase 2: Mechanical Properties Tests

1. For compression test, the block concrete will be tested by using universal testing machine with compressive axial load until failure.
2. For water absorption test, clean block concrete is weighted first before immersion in water for 24 hours. After immersion, the block concrete is wiped and pre-weight. The water absorption is measured by subtracting the initial weight from the final weight and dividing the results by the initial weight.
3. For density test, the block will be weighted
4. For surface morphology test, concrete block is subjected to Fine Emission Scanning Electron Microscope (FE-SEM) and EDX for morphological analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Medical Waste

Medical waste is the type of waste produced by healthcare facilities such as hospitals, dental offices, blood banks, and animal health centres. Medical garbage is also known as healthcare waste. Medical institutions, including clinics, hospitals, and diagnosis and treatment centres, generate toxic waste that can lead to life-threatening illnesses. Medical waste is defined as "any solid waste that is generated in the diagnosis, treatment, or immunisation of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals" (United States Congress, 1988).

The World Health Organisation (WHO) estimates that 20% of these medical wastes contain hazardous elements that may be infectious, poisonous, or radioactive (Brichard, 2002). Policies that specify how waste should be handled for generation, segregation, collection, storage, transportation and treatment should be drafter to prevent the spread of illness (Padmanabhan K. K. et.al, 2018). Potentially infectious substances such as blood and body fluids are part of waste. Waste can be infectious, pathological, sharp, or chemical. Incorrect waste management can pose health dangers to both workers and the general population.

2.2 Medical Waste Fly Ash

Medical Waste Incinerators Fly Ash (MWIFA) is a type of incineration residue that is collected by the waste incinerator system's bag filter and makes up about 3-5 weight percent of the original trash's mass. Leachable alkali chlorides, dioxins, and high amounts of components of carbon and heavy metals. Over 80% of the dioxins in the incinerator are usually found in fly ash. As a result, several nations have classified it as hazardous waste. Due to the relatively high concentrations of carbons and chlorines in MWIFA, its constituents are more complicated than those of Municipal Solid Waste Incineration Fly Ash (MSWIFA), making treatment of MWIFA more challenging. It is necessary to investigate appropriate treatment methods for MWIFA.

The presence of heavy metal enrichment is another feature of MWIFA. In general, syringes, waste plastics, rubber, and medical adhesive plaster are potential sources of the significant amounts of Zn and Cr found in MW. Pb- and Cd-loads in MW are typically increased using PVC polymers. Because aluminium foil, PET, PVC, and PP are often used, the plasticizers and adhesives contained in MW packaging always contain Cu, Zn, and other heavy metals.

Moreover, dental offices, malfunctioning medical facilities, and abandoned batteries all contain Cd and Hg. The common forms of heavy metals in MW include metal elements, metal oxides, volatile metallic chlorides, and sulphates. They are not destroyed during incineration; rather, a tiny percentage turn into volatile metallic vapours and enter the flue gas, which, if APCDs are not able to remove them adequately, may be released into the environment.

Therefore, in a few industries including manufacturing, agriculture, and civil engineering, clinical fly ash can be used to protect the environment. Now, fly ash is utilised in more than 20 million metric tonnes (22 million tonnes) of engineering applications per year. Portland cement concrete (PCC), stabilising soil and road bases, flowable fills, grouts, structural fill, and asphalt filler are examples of common applications in highway engineering.

In PCC applications, fly ash is most frequently utilised as a pozzolan. Pozzolans are siliceous or siliceous and aluminous minerals that react with calcium hydroxide at room temperature to make cementitious compounds when they are finely split and include water. Fly ash enhances the flowability of flowable fill and grout and is a useful mineral filler in hot mix asphalt (HMA) applications due to its distinct spherical form and particle size distribution. Fly ash offers special prospects for usage in structural fills and other roadway applications because of its consistency and quantity in many regions.

The utilisation of fly ash, particularly in concrete, has several important positive effects on the environment. These benefits include, extending the life of concrete roads and structures by improving the durability of the concrete, reducing energy use and greenhouse gas and other adverse air emissions when fly ash replaces or replaces manufactured cement, reducing the quantity of combustion products that need to be disposed of in landfills and conserving other natural.

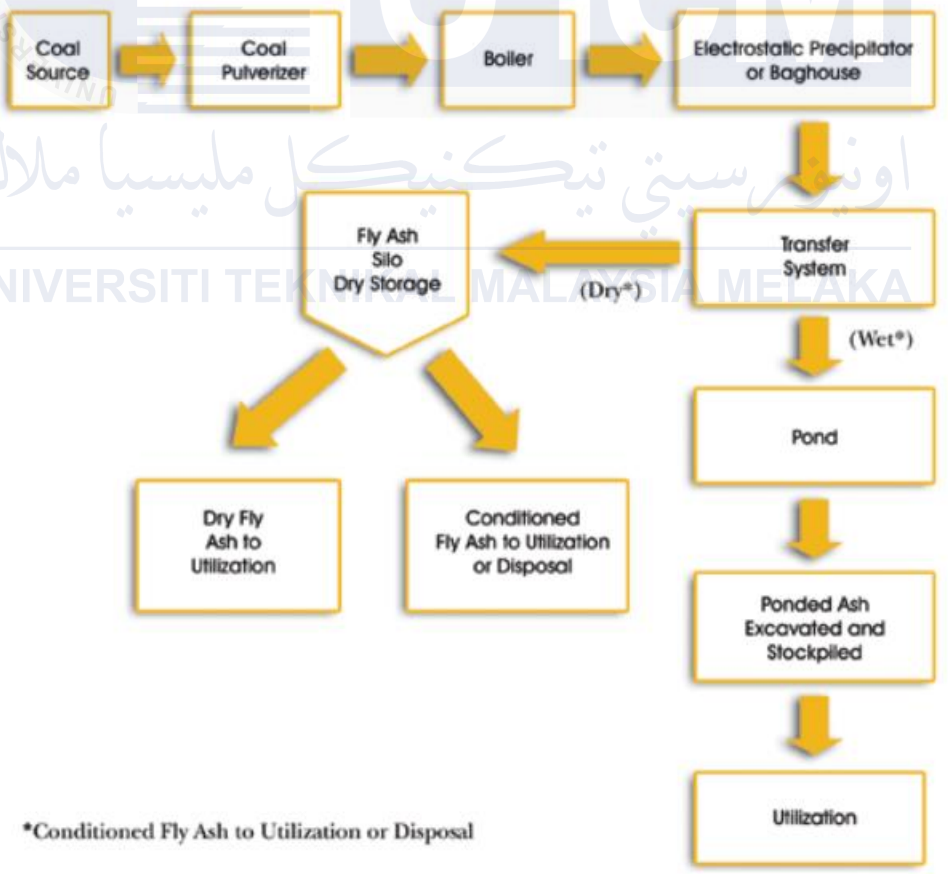

Figure 3: Method of Fly Ash Transfer Can Be Dry, Wet, or Both.

2.3 Healthcare Waste Management

The management of medical waste is a serious concern that requires effective ways to reduce its harmful effects on the environment and public health. Several approaches have been developed to reduce these risks, with segregation emerging as a prominent one. Segregation prevents hazardous waste from contaminating non-hazardous waste, hence lowering toxicity and volume. Furthermore, it improves transportation and aids in the safe disposal of medical waste.

Separating different types of medical waste improves waste management methods. Infectious, pathological, and sharp wastes are separated into labelled containers, simplifying waste handling and disposal procedures. Packaging and labelling processes enable appropriate identification and management of medical waste, while color-coded bags indicate disposal methods.

Disinfection is essential for lowering the toxicity of medical waste. However, caution is advised due to the potential risks connected with various disinfectants. When shredding is combined with chemical disinfectants, solid waste can be effectively treated. However, they are not approved for use with some types of trash, such as pharmaceuticals and chemicals.

Incineration is a useful approach for treating medical waste since it reduces waste mass and volume while transforming it into harmless ash. Portable incinerators such as the "MediBurn" provide easy and efficient solutions for small medical facilities and laboratories. Despite its advantages, incineration has obstacles such as high prices and pollution dangers, needing strict emission controls and effective waste management techniques.

Figure 4: MediBurn

Emerging technologies show potential for transforming medical waste management. Plasma disinfection, for example, provides a low-energy alternative to standard cremation procedures while reducing air emissions. On-site shredding and chemical disinfection equipment are examples of innovations that provide realistic trash treatment options while also lowering transportation costs and improving waste management efficiency.

The proper disposal of medical waste is critical for protecting the environment and public health. We can reduce the environmental impact of medical waste by using new approaches and technology such as segregation, disinfection, incineration, and developing procedures, as well as efficient and sustainable waste management practices. Collaboration among healthcare facilities, waste management authorities, and technology developers is critical for adopting these solutions and tackling the issues associated with medical waste management.

2.4 Concrete

Concrete is a flexible and long-lasting building material made up of various essential elements, namely Portland cement, water, aggregate (such crushed stone or gravel), and additives. A particular kind of concrete known as Portland cement concrete (PCC) uses Portland cement, a fine powder mainly composed of clay, limestone, and other minerals.

As a byproduct of burning, fly ash is frequently used to concrete as an additional cementitious element. Fly ash can partially substitute Portland cement in concrete mixtures, which improves the environment by lowering the need for virgin materials and the greenhouse gas emissions linked to cement manufacturing.

When referring to PCC combined with water and aggregates to create a workable paste that eventually hardens, the word "concrete" is typically used in this sense. Fly ash can improve a variety of concrete mixture characteristics, including workability, strength, durability, and resistance to chemical assault.

To attain the appropriate qualities and performance characteristics, concrete is made by precisely combining Portland cement, water, fly ash, and aggregates. After being combined, the concrete is poured into moulds or forms and left to cure. During this time, a chemical process called hydration occurs in the concrete, binding the constituent parts and fortifying the finished structure.

Because of its strength, durability, versatility, and relative affordability, concrete is used extensively in construction for a variety of purposes, including building foundations, pavements, bridges, dams, and structural parts. Engineers and builders can create high-performance, environmentally friendly structures that match modern construction requirements by mixing fly ash and PCC into concrete mixtures.

2.5 Properties and Process of Concrete

The process of creating concrete bricks involves five steps. Cement, fine aggregates, coarse aggregates, and water are among the basic ingredients that must first be prepared and mixed. Moulding is the second step. The final shape of the concrete is created using concrete moulds (Material Testing Blog, n.d.). After the mould has been filled with concrete, the hydraulic press crushes the concrete into it. Concrete block machines usually use vibration to complete this operation. Casting is the next step, in which the mould is filled with wet cement. Next, the curing process. Curing is the process of keeping concrete for a long time at the right temperature and moisture content. It is so that the right concrete properties can be provided by hydration.

When the potential strength and durability of concrete are fully developed, it has been effectively cured (Role of Concrete Curing, n.d.). For a range of building applications, including pavements and architectural features, they can be moulded into a variety of sizes and shapes. In addition, concrete has a high thermal mass, is energy-efficient, fire-resistant, and provides superior sound insulation, given its low care needs and long-term durability, it is reasonably priced when compared to alternative materials. All things considered, concrete is a dependable and affordable material for a variety of construction jobs.

For this project, the blocks must be cured for 28 days before moving on to the next phase. Finally, concrete blocks need to be used for testing. Its purpose is to guarantee that the concrete satisfies the necessary requirements and design specifications for its intended usage while staying within tolerances (Material Testing - Douglas Partner, 2022). It is necessary to test the concrete block using techniques like compressive and water absorption testing.

2.6 Medical Waste Fly Ash Benefits

Medical waste fly ash has several useful benefits in concrete: it improves workability by reducing friction between cement particles due to its fine particle size and spherical shape, hence making mixing and placing concrete easier; and it reduces the permeability of the mix, thereby improving durability by reducing the possibility of water and harmful chemicals penetrating the material. The addition of fly ash controls the heat of hydration, which is critical in mass concrete pours as it reduces the chance of thermal cracking. Long-term, fly ash contributes to the strength of concrete through pozzolanic reactions, reacting with calcium hydroxide to form additional calcium silicate hydrate (C-S-H). Another environmental benefit of the usage of fly ash is that it reduces waste in landfills and produces a lower carbon footprint in concrete production by partial replacement for Portland cement. Besides, fly ash is economical to procure

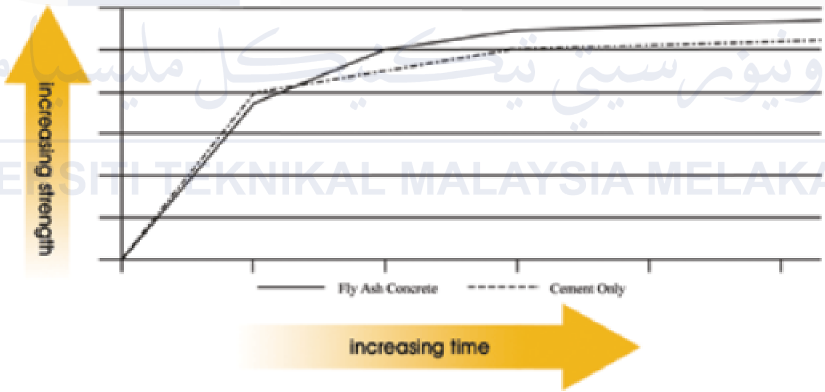

Figure 5: Typical Strength Gain of Fly Ash Concrete

The fly ash reaction with the available lime produces extra binder, which keeps the fly ash concrete stronger over time. In the end, mixtures made to provide strength comparable to that of straight cement concrete mixes at early ages (less than 90 days) will prove to be stronger.

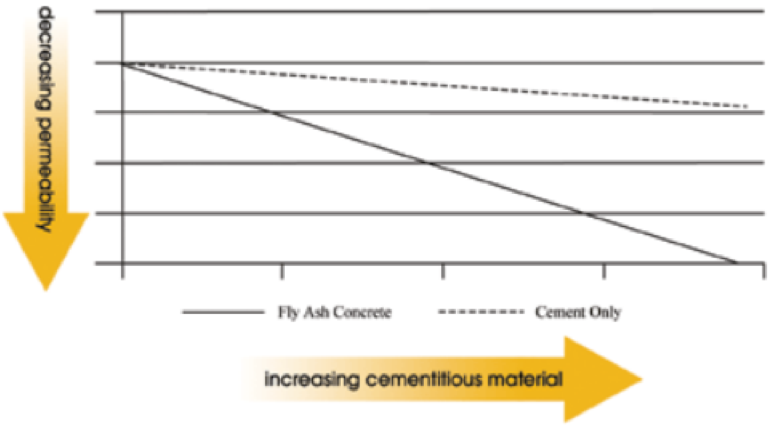

Figure 6: Permeability of Fly Ash Concrete

Concrete's pore interconnectivity decreases because of the reduction in water content and the addition of new cementitious chemicals, which lowers permeability. Improved long-term durability and resistance to different types of deterioration are the outcomes of the decreased permeability.

2.7 Research Gaps

During the examination of sources, an important quantity of information has been analysed regarding the characteristics of clinical fly ash (CFA) towards concrete. As a result, all the concrete's testing and procedures are assessed for use and improvement. Research gaps in the journals and papers are listed in Table 3.

Table 3: Research Gaps

Authors	Key Objectives	Methodology	Key Research Findings
Smith, J. et al. (2022)	Investigate the long-term durability of concrete incorporating high volumes of fly ash.	Long-term field exposure study of concrete specimens with varying fly ash content.	Identified a lack of comprehensive data on the performance of fly ash concrete in real-world environments over extended periods, highlighting the need for further research to assess its durability.
Johnson, A. et al. (2020)	Evaluate the effect of fly ash characteristics on the fresh and hardened properties of concrete.	Laboratory testing of concrete mixtures with varying types and proportions of fly ash.	Found inconsistencies in the influence of fly ash properties on concrete performance, indicating the necessity for more systematic investigations to understand the underlying mechanisms.
Garcia, M. et al. (2019)	Assess the environmental impact of large-scale fly ash utilization in concrete production.	Life cycle assessment (LCA) of concrete incorporating different percentages of fly ash.	Identified gaps in the existing literature regarding the holistic environmental implications of widespread fly ash

			utilization, emphasizing the need for comprehensive LCAs considering various environmental indicators.
Patel, S. et al. (2021)	Investigate the performance of fly ash-based geopolymer concrete in aggressive chemical environments.	Accelerated laboratory testing of geopolymer concrete specimens exposed to chemical solutions simulating harsh environmental conditions.	Revealed limited data on the chemical resistance of fly ash-based geopolymers, indicating the necessity for further research to optimize their durability in aggressive settings.
Wang, L. et al. (2018)	Explore the economic feasibility of large-scale utilization of fly ash in concrete production.	Cost-benefit analysis of incorporating fly ash in concrete mixes from the perspective of concrete producers and end-users.	Identified knowledge gaps in assessing the long-term economic benefits and potential market barriers hindering the widespread adoption of fly ash in concrete, highlighting the need for more comprehensive economic studies.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the research study's methodology is elucidated. It outlines how the methodology will be implemented. The procedures involve material preparation, experimental testing and analysis. This chapter discusses how the methodology will be carried out. The purpose of this report is to confirm that by using the proper methodologies during laboratory experimentation, the goal of this research study may be successfully attained. The procedures employed include material preparation, experimental testing, and analysis.

3.2 Overview of the Methodology

Section 3.3 explains the process of collecting fly ash (FA). Section 3.4 will express the grinding process utilising a crusher machine accessible at Fakulti Teknologi Kejuruteraan Industri dan Pembuatan (FTKIP), UTeM. Sand, coarse aggregates, and FA are sieved using a sieve machine. Sand and FA use fine meshing siever with sizes of 2.36mm, 1.18mm, 0.6mm, 0.3mm, and 0.15mm. The coarse aggregate size options include 20mm, 14mm, 10mm, and 5mm. Section 3.5 covers the preparation of cement, water, fine aggregates, and coarse aggregates. The mould is casted at a size of 100mm x 100mm x 100mm, as specified in section 3.6. this is the size of concrete block that will be used as specimens in the tests.

Testing to measure the physical and mechanical properties of the specimens includes Compressive Test, Water Absorption Test, Density Test, FE-SEM Test, EDX Test with interpretations at 3.7.1, 3.7.2, 3.7.3, 3.7.4, 3.7.5. Each test includes three samples with varying CFA ratio percentages (10%, 20%, and 50%). There will be 54 specimens for all the tests with its controlled measurements. All specimens are tested and analysed for improved mechanical performance. Figure 3.2 displays the flowchart of the research investigation.

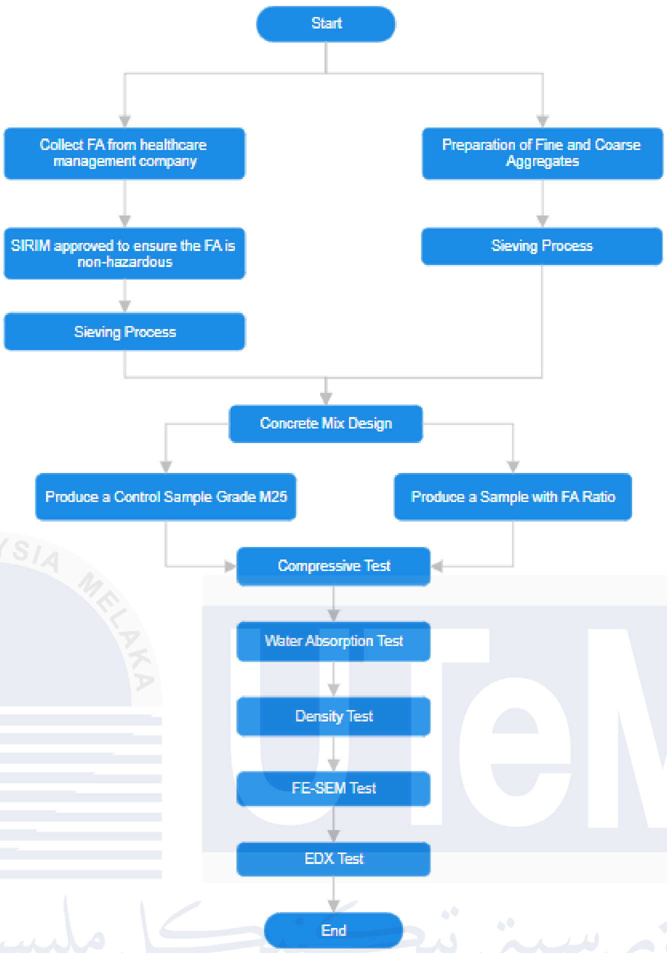

Figure 7: Flowchart of the Research Investigation

3.3 Collecting Medical Fly Ash from Healthcare Waste Management

Medical Fly Ash comes from a healthcare waste management company nestled in Bukit Rambai, Melaka. This company is not just about business, it is about making sure hospitals across the southern peninsula of Malaysia are kept clean and safe. They do it all from collecting to storing, transporting, and properly disposing of medical waste. Not to mention, they take charge of managing all the supplies and containers needed to handle medical waste efficiently. On the day of collecting, managed to gather around 5 kilograms of fly ash (FA).

3.4 Sieving Process

Sieving process involves the process of passing a material through smaller sieves to measure its fineness modulus and grain size distribution. Sieve analysis test was carried out according to BS 882:1992 for fine and coarse particles. The sample should be cleaned by blowing dry air before conducting the sieving process. After that, the samples are baked in an oven for more than 24 hours to guarantee they are entirely dry. Next, clean the sieve shaker with a brush to remove any contamination or particles. The weight of the receiving pan is first recorded, followed by the weight of each sieve size. Position the sieves with the largest opening on top and the smaller opening on the bottom. Sieve time is set at 10 minutes, and the final weight retained on the sieve is measured.

3.5 Preparation of Material

In this thorough study, we need to carefully prepare a variety of raw materials to ensure the flow process runs smoothly. Creating a concrete block that incorporates FA involves precisely combining several essential elements: cement, fine and coarse aggregates, FA, and water.

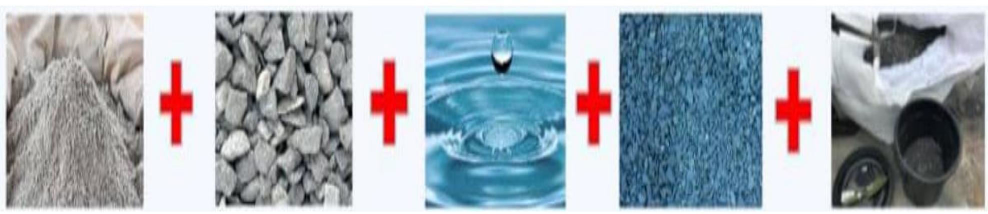

Figure 8: Combination for Mortar

3.5.1 NS Composites Cement

MS EN 197-1 dictates that NS Portland - Limestone Cement shall be manufactured by grinding Portland cement clinker, limestone, and other inorganic materials under a tight quality control system. NS Portland - Limestone Cement is appropriate for all general-purpose applications. Some of its advantages include improved workability, reduced bleeding, and less environmental contamination. Cement bags were purchased from a local supplier at Ayer Keroh, Melaka. The price of cement per bag is RM 21.00. Table 4 gives specifications for NS Composites Cement. Figure 9 shows a package of NS Composites Cement.

Table 4: Specifications for NS Composites Cement

ITEM	MS EN 197-1 CEM II/B-L 32.5R	TYPICAL TEST RESULT
SULPHUR TRIOXIDE SO3	3.5 Max	
CHLORIDE CONTENT	0.1 Max	
INITIAL SETTING TIME	75 Min	
COMPRESSIVE STRENGTH	10MPa min (2 Days)	17.6MPa (2 Days)
	32.5MPa – 52.5 MPa (28 Days)	9.6MPa (28 Days)
SOUNDNESS	10mm max	1.01mm

Figure 9: NS Composites Cement

3.5.2 Natural Fine Aggregates (Sand)

River sand can be utilised as fine aggregates in a concrete mixture. Natural fine aggregates typically measure less than 4.75mm, according to BS410. BS882:1992 requires graded sand to have a 100% passage rate for 600µm openings. Sand is dried in an oven at 110ºC ± 5ºC for at least 24 hours. Sand is sieved through a 600µm hole once it had dried. The sifting method for sand is detailed in BS882:1992. The sieve sizes utilised for natural fine aggregates include 2.36mm, 1.18mm, 600µm, 300µm, 150µm, and pan. Figure 10 shows a sieve machine for fine aggregates.

Figure 10: Sieve Machine for Fine Aggregates

3.5.3 Coarse Aggregates

The coarse materials in this project were good in quality and easy to be accessed as it was taken from a supplier based in Ayer Keroh, Melaka. Gravel that is used in this study was appropriate for our purpose in view of its maximum particle size being 20 mm.

Coarse aggregates to BS882:1992 would be utilized in the protection of the integrity of the experimental protocols that we adhered to pertinent regulations. This British Standard describes the requirements for aggregates to be used in construction: size, strength, durability, and general quality.

We used a set of sieve sizes for the sieving study to accurately identify and separate the aggregate particles. The sieves used were of sizes 20 mm, 14 mm, 10 mm, and 5 mm. A pan at the bottom for collecting smaller particles was used. This wide range made it possible to conduct a complete gradation analysis and guarantee that the gravel's particle size distribution complied with the project's specifications.

The research study aimed to improve the quality and completeness of the project by ensuring that the results obtained were reliable and replicable, meeting these standards through rigorous testing. Figure 11 shows the coarse material sieve shaker.

Figure 11: Sieve Machine for Coarse Aggregates

3.6 Designing a Concrete and Mix Proportion

Many steps are involved in the design of a concrete block that measures 100mm x 100mm x 100mm. It has three processes: moulding, casting, and curing. Moulds will help mould concrete into the form of cubes. A mould, which is usually made from wood, metal, or plastic, is generally poured with cement paste. The mould must be easily removed from the concrete.

Following that, the casting process proceeds. The casting technique involves pouring cement paste into a mould or formwork and allowing it to harden. Curing cement refers to the process of hardening and strengthening concrete. This entails keeping the concrete moist after pouring, usually with water. This strengthens the connections between cement particles in concrete, increasing its durability. This process takes around 28 days to fully harden. The concrete will achieve its maximum strength. Medical fly ash is employed at a ratio of 10%, 20%, and 50% to substitute natural fine aggregates. The weight ratio of cement, coarse particles, and water remain unchanged.

3.7 Testing

Concrete can support large loads, which is why structural engineers use it so often. Concrete must be tested to confirm its strength and durability and to make sure it satisfies the necessary requirements before being used in construction projects. This study concentrates on the vital component of assessing the performance of concrete at one critical curing times: twenty-eight days. Through these tests which is Compressive Test, and few more, we can determine how the properties of the concrete have evolved over time, finally guaranteeing its suitability for structural uses.

3.7.1 Compressive Testing

A compression testing machine that complies with the requirements given in BS 12390-3:2019 was used in this investigation to perform the compressive strength test. Since the sample is being forced to fail and its structure is being disrupted, this test is categorised as destructive. This kind of test is done to find the maximum compressive strength that the material is capable of handling. This approach is widely used in materials engineering and construction to guarantee that performance and quality criteria are fulfilled. It is essential for comprehending the behaviour of the material under load. Figure 12 below show the compression testing machine used in this project.

Procedure for compression strength test:

1. Wipe the excess of moisture from the surface of the specimen before placing in the testing machine.
2. Wipe all testing machine bearing surfaces clean and remove any loose grit or other extra materials from the surfaces of specimen.
3. Position the specimen that the load is applied perpendicularly to the direction of casting.
4. Centre the specimen with respect to the lower platen to an accuracy of ±1% of designated size of cubic.
5. A constant rate of loading was select within the range of 0.2MPa to 1.0MPa.
6. Apply load to specimen without shock and increase continuously, at the selected constant rate ±10%, until no greater load can be sustained.
7. Record maximum load indicated.

Figure 12: Compression Testing Machine

3.7.2 Water Absorption Test

Water absorption test is one of the important techniques to determine the sorptivity of concrete surfaces. The rate at which water enters the concrete depends on this decision. In the experiment, a time-dependent mass gain in the concrete samples due to water absorption is measured when the face of each specimen is exposed to water. Due to this methodology, correct data about the absorption of water in such rates can be acquired. In executing this test, much rigour needs to be paid to the following to ensure that BS, 1881-122: 2011, is followed so uniformity and dependability of the results maintain. It offers in detail specifications and steps taken for test comparison and for conformity with quality necessary requirements.

Procedure of water absorption test:

1. Place specimen in the drying oven with not less than 25mm from any heating surface for 72 ± 2 hours.
2. On removal from oven, cool the specimen for 24 ± 0.5 hour in the dry airtight vessel.
3. Weight each specimen and immediately completely immersed in the tank with there is 25 ± 5 mm of water over the top of the specimen.
4. Leave the specimen immersed in the water for 30 ± 0.5 minutes.
5. Remove any excess water from the surface and record the weight of specimen.

Measured absorption of each specimen is calculated as the increase in mass resulting from immersion that is expressed as a percentage of the mass of dry specimen. Figure 13 below show the schematic representation of water absorption test.

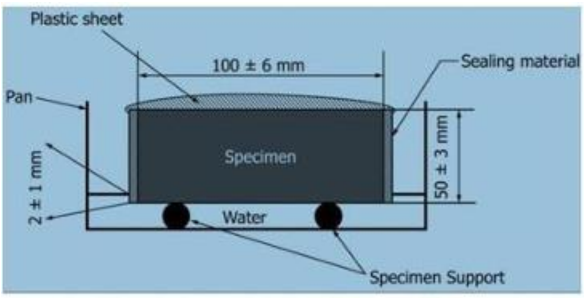

Figure 13: Schematic Representation of Water Absorption Test

3.7.3 Density

The density of an object is the amount of space that an object occupies with respect to its mass. This property becomes very important in different applications, one of which is in civil engineering, particularly in the assessment of the physical characteristics of materials to be used or added in the concrete, which includes FA. A dense object compactly and heavy means that the mass contained in each volume of the object is great.

The density of concrete is one of the most critical factors that could affect the overall solidity and structural integrity of concrete. Different densities, which may arise from the mix of concrete, could affect the strength and durability of the resultant product. The density of concrete is done by measurement and standardized to some rules, such as BS EN 12390-7:2009. This standard helps in the assurance of quality and compliance with the building code through the realization of consistency and reliability during the testing of concrete density.

It is in understanding and controlling concrete density, then, that projects in building will function as they need to and endure long. Their density principles, therefore, in preparing and applying the said concreting materials, have been carefully adhered to and monitored accordingly.

Density measurement procedure:

1. Weigh the specimen as received and record the value in kilogrammes.
2. Check the dimensions and compute the cube's volume in m3.
3. Apply the formula to calculate the density of a specimen based on its mass and volume.

$$Density = \frac{Mass}{Volume} (\frac{kg}{m^3})$$

3.7.4 Microstructural Analysis Using FE-SEM

This microstructural examination is usually employed as a stepping stone while making evaluations of physical and chemical features in materials at both micro and nano scales. FE-SEM will be a broad technique that contains high-resolution imaging and thorough internal-external microstructures of the materials under these examinations.

Careful sample preparation is the first step in the procedure. The cleaning up of impurities from the material sample is performed to provide precise imaging for FE-SEM investigation. It could be mounted and polished, depending on the type of material, to provide a smooth surface fitting for high-resolution analysis. Non-conductive materials are normally coated with a thin coating of a conductive material such as carbon or gold to prevent charging under an electron beam.

FE-SEM produces a focused electron beam for scanning on the sample surface. These electrons interact with the material and, due to their interaction, yield signals that may include secondary electrons, backscattered electrons, and characteristic X-rays. Such emitted signals bear information on the elemental mapping, composition of materials, and topography.

It ensures further enhancements in the analyses by means of image-processing tools like ImageJ or FE-SEM software. First, high-resolution photographs for this research are taken at different magnifications. After that, quality enhancement is carried out on these pictures by enhancing their contrast, removal of noise, correction of brightness, among other techniques known as preprocessing operations. Observation of the picture properties in detail is further ensured with the usage of Image J or any software to attain data on the distribution of phases and pore structure; particle size-morphology by the end.

Examples of quantitative data retrieved and statistically analysed include particle size distribution, porosity, and elemental mapping. Such knowledge is very important in explaining the mechanical, chemical, and durability properties of a material as related to its microstructure. For example, in concrete applications, FE-SEM analysis can reveal how the aggregates bond to the cement paste, the production of hydration products, and the propagation of microcracks.

Results from FE-SEM studies are usually compiled into highly detailed reports, complete with correct measurements, high-resolution images, and visualizations such as tables and graphs. The results drawn from such studies have then been compared with the performance indices of the material to find relationships and indicate areas for improvement.

FE-SEM, for its unparalleled precision and flexibility, has emerged as one of the prime tools for state-of-the-art research on materials. It will be able to reveal more about material behaviours that may lead scientists and engineers to new ideas and enhancements by pushing the boundaries in various manufacturing industries, material sciences, and even construction.

Figure 14: FE-SEM Testing Machine

3.7.5 Elemental Composition Analysis Using EDX

EDX is a well-established analytical technique for material basic composition determination, especially in the studies of the microstructural characteristics of concrete containing supplementary elements such as fly ash. This technique is often conducted along with SEM to provide morphological and compositional data and has been instrumental in providing a great amount of information on the chemical aspects related to microstructures in concrete.

The concrete specimens containing fly ash are collected, cured, and sectioned into appropriate sizes in the EDX examination process. The samples are then polished to a flat surface and covered with a conductive coating to enhance the interaction between the electron beam and the sample in the SEM-EDX test.

After preparation, the samples are analysed by a SEM that is equipped with an EDX detector. The material responds to a high-energy electron beam by emitting characteristic X-rays corresponding to specific components in the sample. Processing of the resulting X-ray spectra enables determination and measurement of elemental composition of different phases present in the microstructure, including the fly ash particles, hydration products, and the unreacted cementitious components.

Specialised software is used to analyse the gathered spectral data and produce element maps and distribution profiles. Some of the key parameters extracted from the EDX study include:

1. Elemental composition, such as Si, Ca, Al, Fe, and other oxides in cement and fly ash
2. Element weight and atomic per cent are used in assessing hydration efficiency and chemical homogeneity.
3. Phase identification: To distinguish between unhydrated fly ash, calcium-silicate-hydrate (C-S-H) phases and secondary reaction products.

EDX study results reveal the pozzolanic reactivity of fly ash in concrete, something very crucial and helpful for the researchers to understand how the chemical composition of the material affects its sustainability, durability, and mechanical strength. Inclusion of silica and alumina improves long-term durability due to secondary hydration processes, while the high calcium content in fly ash can contribute toward strength development at an early age.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction of Result and Discussion

The results obtained from experiments conducted are hereby further analysed and discussed, each test in this chapter is performed under a variety of tests performed. The tests were carried out according to their respective standards on requirements for acceptance and accuracy. All of these were subjected to the specified curing periods-28 days, with which a fair and enough time is spent in developing specimens according to their characteristics. These dates initiate curing, so proper monitoring and study of changes in characteristics may be undertaken during the development process. With such different casting dates, a relative assessment of how differing mix design, curing condition, and types of additives alter the total performances of these various concrete specimens could be easily enabled.

The results obtained from the experiments are analysed and discussed in this chapter. Each test was performed under various conditions and conducted in accordance with the respective standards to ensure accuracy and compliance with acceptance criteria. The specimens were subjected to a standard curing period of 28 days, allowing sufficient time for their properties to develop as per their designed characteristics. The variation in casting dates facilitated a comparative assessment of how differences in mix design, curing conditions, and types of additives influence the overall performance of the concrete specimens. These analyses provide valuable insights into the performance and durability of the tested materials, contributing to a deeper understanding of their behaviour under different conditions.

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Table 5: Blending Percentage to Produce Concrete – Batch 1

CONCRETE MIX	**MIX PROPORTIONS (KG/M3)**		**FINE AGGREGATES (SAND)**	**COARSE AGGREGATES**	**WATER**	**WATER – TO – CEMENT RATIO (W/C)**
	Replacement with CFA (%)	Cement				
FA0	0	0.5	0.5	1	0.23	0.46
FA10	10	0.45	0.5	1	0.23	0.46
FA20	20	0.4	0.5	1	0.23	0.46
FA50	50	0.25	0.5	1	0.23	0.46

The mix proportions used in the second batch are given in Table 6. We were able to resolve the problems of solidification and setting time as observed in the previous batch. It was far beyond our initial expectations in terms of drying and solidification capabilities. The primary reasons for this improvement were the addition of $CaCl_2$ and a superplasticizer, each playing a significant role in ensuring the maximum degree of hydration with minimum setting time.

Notwithstanding these improvements, an unexpected problem arose where the compressive strength of the second batch was below prediction. What this result would suggest is that while the changes had a positive effect on workability and cure efficiency, they may also have affected the overall structural integrity of the mixture. Later in this paper, a comprehensive analysis of this problem, including probable causes and proposed fixes, will be given in detail in the section on compressive strength testing.

Table 6: Blending Percentage to Produce Concrete – Batch 2

CONCRETE MIX	**MIX PROPORTIONS (KG/M3)**		**FINE AGGREGATES (SAND)**	**COARSE AGGREGATES**	**WATER**	**WATER – TO – CEMENT RATIO (W/C)**	**2% OF ADDITIVES**	
	Replacement with CFA (%)	Cement					$CaCl_2$	Plasticizers
FA10	10	0.45	0.5	1	0.23	0.46	0.032	0.032
FA25	25	0.375	0.5	1	0.23	0.46	0.032	0.032
FA50	50	0.25	0.5	1	0.23	0.46	0.032	0.032

4.2 Sieving Analysis

Sieve analysis is the determination of the distribution of the various sizes of the particles in fine and coarse aggregates through the passing of materials within a sequence of sieves, each having smaller mesh sizes than the preceding one. It is a technique used to provide an assessment of the characteristics of grading in aggregate, which are quite crucial in the performance of concrete. The purpose of sieve analysis is usually to determine the fineness modulus and the grain size distribution, which indicates whether the aggregates are within the specification limits for use in construction.

Sieve analysis was performed strictly in accordance with BS 882:1992, a British Standard which specifies requirements for the grading limits of fine and coarse aggregates for use in concrete. These standardized procedures have helped check consistency, quality, and suitability of aggregates for the purpose of construction. Proper grading of aggregates ensures adequate workability, strength, and durability of concrete with minimal defects like segregation, high water demand, and poor compaction. This analysis delivers vital data in the development of optimum mix designs as it ensures the aggregates used support the mechanical properties and long performance sought in concrete.

4.2.1 Sieving of Fine Aggregates (Sand)

To guarantee precise and reliable outcomes, the minimum sample weight for every cycle of the fine aggregate sieving process is 700 g. This is a sufficient sample size for an accurate evaluation of the particle size distribution.

The graphical representation of the sand sample results in Figure 15 suggests that there is no large gap between the grain diameters of these sieves. The weight of the whole sample (710 g) in this sieve analysis was 0.71 kg. Less than 0.2% separated the sample weight measured before and after the sieve operation, suggesting that very little material was lost throughout the process. The final weight of the sand sample was approximately 0.70 kg (700 g), which further indicated the accuracy and reliability of the sieving process.

To determine if the fine aggregates meet the requirements, BS 882:1992 permits the percentage passing limits as tabulated in Table 7 for various sieve sizes. This will conclude whether the sand sample meets the grading specifications for its use in concrete to achieve the appropriate mix's workability, strength, and durability.

One of the major conclusions derived from the analysis is that at an effective sieve size of 1.18 mm, an extremely high percentage of sand and about 35.21% of the weight of the sample, is retained. Thus, within this small range, a large number of fine particles is taken up, which might affect the material's grading and its performance in concrete.

Table 7: Passing Percentage of Fine Aggregates According to BS882:1992

SIEVE SIZE	**PERCENTAGE BY MASS PASSING BS410 SIEVE**			
	Overall Limits	Additional Limits for Grading		
		Coarse	Medium	Fine
10MM	100	-	-	-
5MM	80-100	-	-	-
2.36MM	60-100	60-100	65-100	80-100
1.18MM	30-100	30-90	45-100	70-100
600MM	15-100	15-45	25-80	55-100
300MM	5-100	5-40	5-48	5-70
150MM	0-15	-	-	-

Table 8: Result for Sieving Analysis for Natural Fine Aggregate

SIEVE SIZE, MM	SIEVE WEIGHT, KG	SIEVE RETAIN WEIGHT, KG	WEIGHT RETAIN, KG	PERCENTAGE WEIGHT RETAIN, %	CUMULATIVE RETAIN, %	PASSING PERCENTAGE, %
10.00	0.36	0.36	0.00	0.00	0.00	**100.00**
4.75	0.37	0.38	0.01	1.41	1.41	**98.59**
2.36	0.40	0.53	0.11	15.49	16.9	**83.1**
1.18	0.38	0.61	0.25	35.21	52.11	**47.89**
0.60	0.35	0.52	0.18	25.35	77.46	**22.54**
0.30	0.32	0.37	0.06	8.45	85.91	**14.09**
0.15	0.33	0.43	0.08	11.27	97.18	**2.82**
PAN	0.24	0.25	0.02	2.82	100.00	**0.00**
	SUM		**0.71**	**100.00**	**-**	**-**

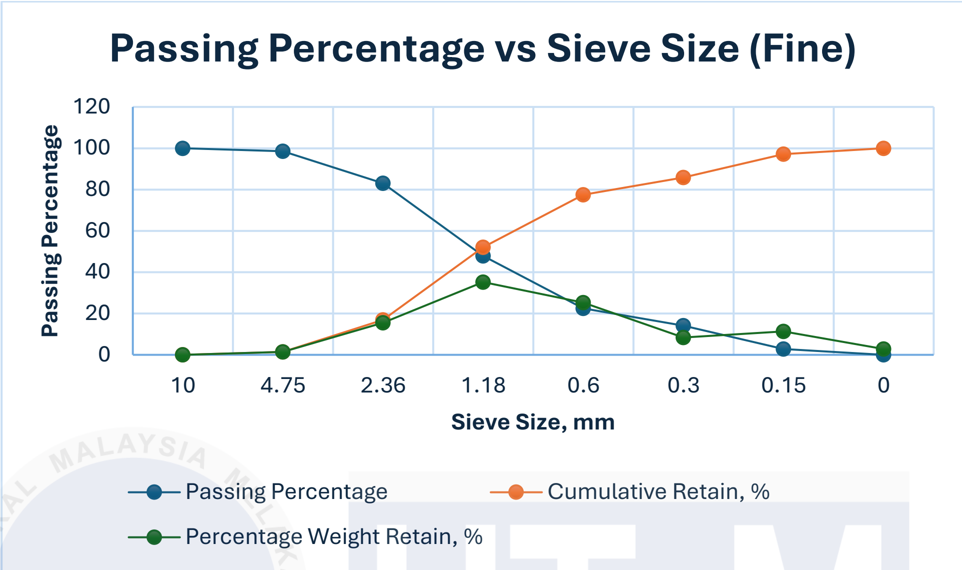


Figure 15: Result for Passing Percentage of Natural Fine Aggregates

The "Passing Percentage vs. Sieve Size" graph gives data on the size distribution of particles in the fine aggregate sample. The blue line, which stands for the passing percentage, with an increase in sieve size, it does indicate that at earlier stages of sieving, coarse particles are retained, and finer ones pass through small sieves. For bigger sizes of sieves, the curve nears 100%, reflecting that the major portion is made up of tiny particles.

The orange line, showing the Cumulative Retain Percentage, decreases with an increase in filter size, the starting point lies at 100% on the smallest size of the sieve. This suggests that a high amount of the material was retained on the finer sieves and therefore that the sample is majorly composed of small-sized particles. It will be observed that around the 1.18 mm sieve size, the green line, which represents Percentage Weight Retain, reaches its peak and then declines. This is an indication that at larger sieve sizes, the retain is smaller and most of the sample particle size distribution is concentrated at this range.

This study indicates that the aggregate sample is majorly composed of fine particles, with a small number of coarser ones. The material is leaning towards being a finer aggregate, as can be seen by the clearly defined peak in weight retention at the finer sieve sizes. Since some coarse particles are going to be added to the mix to contribute to the interlocking effect and general stability, it will influence the workability of the concrete, strength, and durability.

4.2.2 Sieving of Coarse Aggregates

Particles larger than 4.75 mm but typically ranging in diameter from 9.5 mm to 37.5 mm are classified as coarse aggregates. These particles are highly influential in the overall strength and stability of concrete mixtures. In this test, the sieving method was used in ensuring uniformity in particle dispersion with coarse aggregates of nominal size of 20 mm.

Each cycle must have a minimum weight of 3 kg for the sieving to be considered accurate. In this experiment, a 3.51 kg sample of gravel was sieved. At the end of the process, the weight was 3.51 kg, which means there was not much material lost. The graphical representation of the sieving is as shown in Figure 16, showing the distribution of the different sizes of aggregates. With an overall weight of 1.439 kg, the maximum quantity of gravel was retained at the 10 mm sieve size.

This tells us that the biggest portion of the aggregate is within this size range. To determine if the gradation of this material meets standard grading specifications, refer to Table 9 which gives the permissible limits for coarse aggregates in accordance with BS 882:1992. The detailed results of the sifting process for the coarse aggregates used in this research are then presented in Table 10.

In general, the coarse aggregates used in this study are deemed suitable for the intended experimental use based on the sieve analysis and meeting the BS 882:1992 standard. Their suitability in concrete mix design is ensured by their particle size distribution, which meets the minimum requirements.

Table 9: Percentage by Mass Passing BS410 Sieve for Nominal Size

SIEVE SIZE	**GRADED AGGREGATES**			**SINGLE-SIZED AGGREGATES**		
	40 mm to 5 mm	20 mm to 5 mm	14 mm to 5 mm	40 mm	20 mm	**10 MM**
37.5MM	90 to 100	100	-	85 to 100	100	-
20MM	35 to 70	90 to 100	100	0 to 25	85 to 100	-
14MM	25 to 55	40 to 80	90 to 100	-	0 to 70	**100**
10MM	10 to 40	30 to 60	50 to 85	0 to 25	0 to 25	**85 TO 100**
5MM	**0 TO 10**	**0 TO 10**	**0 TO 10**	-	**0 TO 5**	**0 TO 25**

Table 10: Result of Sieving Process Coarse Aggregates

SIEVE SIZE, MM	SIEVE WEIGHT, KG	SIEVE RETAIN WEIGHT , KG	WEIGHT RETAIN, KG	PERCENTAGE WEIGHT RETAIN, %	CUMULATIVE RETAIN, %	PASSING PERCENTAGE, %
20.00	1.556	1.692	0.236	6.72	3.72	**96.28**
14.00	1.252	1.857	0.705	20.09	26.81	**73.19**
10.00	1.170	2.509	1.439	41	67.81	**32.19**
5.00	1.263	2.394	1.130	32.19	100.00	**0.00**
2.36	1.037	1.037	0	0	100.00	**0.00**
PAN	0.878	0.878	0	0	100.00	**0.00**
	SUM		**3.51**	**100.00**	**-**	**-**

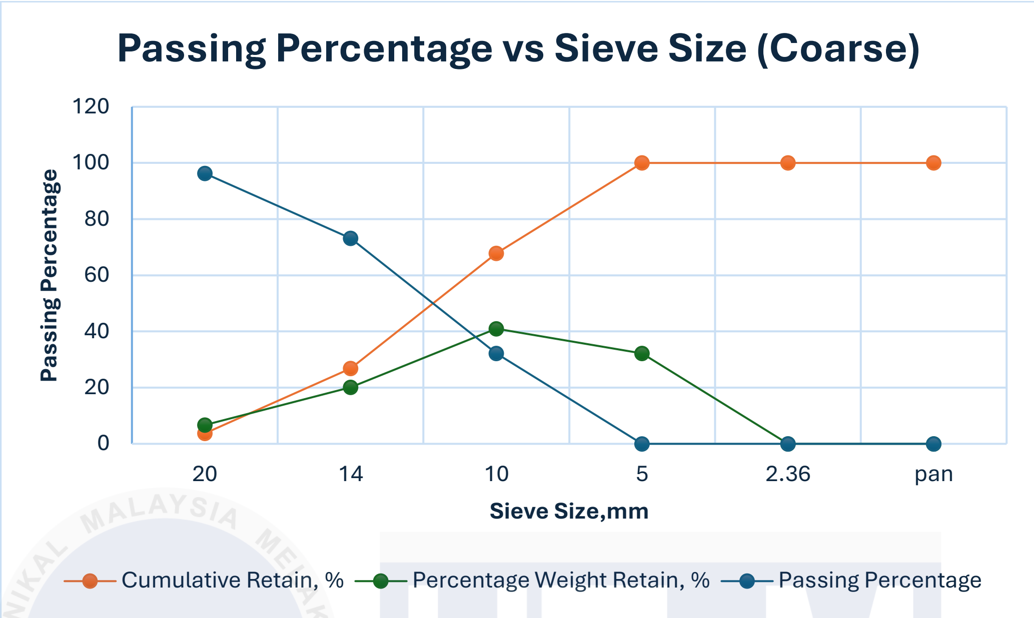


Figure 16: Result for Passing Percentage of Coarse Aggregates

This graph approximates the sieve analysis for particle size distribution of the coarse aggregate sample, as shown in this "Result for Passing Percentage of Coarse Aggregates". Larger particles stay held on the sieves, but smaller aggregates are allowed to flow through as can be perceived in this line of the blue trace. The percentage does have a downtrend as the sieve is getting smaller, resulting less aggregates can pass through. This curve tends closer to 0% to satisfy larger particulates.

The orange line shows the Cumulative Retain Percentage that, as anticipated, rises as the filter size increases from a small fraction close to 0%, and therefore reflects that most material will be retained on larger-sized sieves, thus confirming the preponderance of coarse particles in the sample. The green line, which represents the Percentage Weight Retain, reaches its peak at the mid-range sieve size and then starts to decline. That would tend to indicate that most of the sample appears to fall within that size range.

The size, shape, strength, and durability are some of the major characteristics of coarse aggregates. Cements, fine and coarse aggregates must be mixed to form strong concrete. One type of coarse aggregate used in improving the overall performance of concrete is gravel. Some of its primary functions include bulk and volume, strength, and load-bearing capacity. This would be due to the interlocking nature of the particles preserving structural integrity and increasing strength, gravel is also an economical option as it can be obtained locally.

It can be concluded that the aggregate sample has very little fine material and is mostly composed of coarse particles. Concentrations of weight retention around a specific sieve size indicate that the material may not be properly graded. It is required to compare this aggregate's appropriateness for construction to the grading standards of BS 882:1992.

4.3 Density Result

Table 11: Density Result for Batch 1 and 2

Concrete Mix	Date of Cast	Dimension (mm)	Volume (m^3)	Mass (kg)	Density (kg/m^3)
FA 10	13/08/2024	99.39x99.04x99.06	0.000975	2.022	2073.846
FA 20	13/08/2024	98.86x100.94x98.78	0.000986	2.124	2154.158
FA 50	13/08/2024	98.73x100.40x98.90	0.000980	1.949	1988.776
FA 10 + Add	30/09/2024	96.61x98.77x99.13	0.000946	1.864	1970.402
FA 25 + Add	30/09/2024	103.79x98.33x100.5	0.001026	2.074	2021.442
FA 50 + Add	30/09/2024	93.37x99.10x99.57	0.000921	1.737	1885.993

Table 11 presents the density results for two different concrete mixes which is Batch 1 and Batch 2. Batch 1 was casted on 13/08/2024 while Batch 2 was casted on 30/09/2024. Few key parameters are recorded including dimensions (mm), volume (m^3), mass (kg), and density (kg/m^3) for each sample. The density values are ranging from 1885.993 kg/m^3 to 2154.158 kg/m^3, reflecting variations in composition and material properties across the mixes. The highest density of 2154.158 kg/m^3 is observed in FA 20, while the lowest, 1885.993 kg/m^3, is recorded for FA 50 + Add.

Comparing FA 10 and FA 10 + Add gives 2073.846 kg/m^3 and 1970.402 kg/m^3, respectively. Addition of an additive decreases the density, indicating that the additive may have altered the composition or compactness of the mix. Comparing FA 50 + Add and FA 50 gives 1885.993 kg/m^3 and 1988.0776 kg/m^3, respectively. A similar trend can be observed to support the finding that additives tend to decrease density.

The volume of samples ranges from 0.000921 m^3 to 0.001026 m^3, which is relatively constant and reflects uniform sample preparation. The highest volume is 0.001026 m^3 for FA 25 + Add, while the relatively high density is 2021.442 kg/m^3; this shows that volume does not solely determine density. Mass values agree with density trends, as heavier samples normally have higher densities, which agrees with expectations based on concrete mix compositions.

As shown in Figure 17, since additives generally tend to have a density-reducing effect, density fluctuations can reflect mix composition. Maximum density is evidenced through FA 20, either with reduced porosity or a tighter packing of the particles. Such a phenomenon points to the mix design effects on concrete's ultimate density and thereby influences its strength, durability, and overall performance in the construction context.

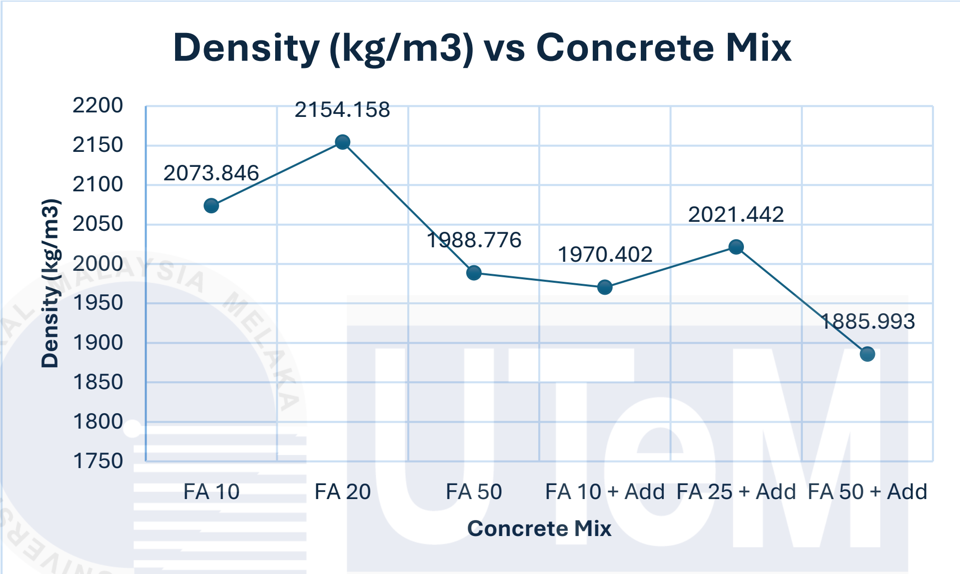


Figure 17: Density vs Concrete Mix

Furthermore, higher density improves strength and durability but may increase weight, reduce workability, and raise costs. The right balance depends on the project’s needs, like load capacity and exposure conditions. Table 12 simplifies the advantages and disadvantages of density for concrete.

Table 12: Advantages and Disadvantages of Density for Concrete

ASPECT	ADVANTAGES	DISADVANTAGES
STRENGTH	Higher strength and durability	Increased weight requiring stronger foundations
POROSITY	Reduced porosity, better water resistance	Lower workability, harder to mix and place
RESISTANCE TO WEAR	Better resistance to wear and abrasion	More expensive materials (e.g., fine aggregates)

4.4 Water Absorption Result

The water absorption tests were conducted to determine the absorption characteristics for Batches 1 and 2. The test seeks to determine the quantity of water that the samples can absorb over a specific duration. To study the long-term capability of the materials in absorbing water, the results were obtained after the samples had undergone a 28-day water curing. Summary of results in Table 13 highlights, with an emphasis on the differences in absorption rates between the two batches. These results represent new information that is valuable for material durability and lifespan against water deterioration.

Table 13: Result for Water Absorption

CONCRETE MIX	BATCH	INITIAL MASS (KG)	MASS AFTER OVEN DRY, W1 (KG)	MASS AFTER SPECIFIED IMMERSION, W2 (KG)	WATER ABSORPTION % [(W2-W1)/W1) X 100%]
FA 10	1	1.992	1.901	2.036	7.10
FA 20		2.145	2.029	2.127	4.83
FA50		1.980	1.860	2.026	8.92
FA 10 + ADD	2	1.906	1.795	1.937	7.91
FA 25 + ADD		1.928	1.815	1.910	5.23
FA 50 + ADD		1.921	1.789	1.951	9.06

As the curing period is for twenty-eight days, each mixing ratio produces different water absorption percentage. Water absorption was studied to find the capillary action in concrete. The method to verify that water flows through concrete is called capillary action. The variation in water absorption results among those ages may be because of the different forms of the C-S-H gel. This gel form can fill the cracks while keeping water or any other liquid out of the concrete. Besides that, the calcium silica hydrate decreases the size of the pores and seals the barrier of the cement.

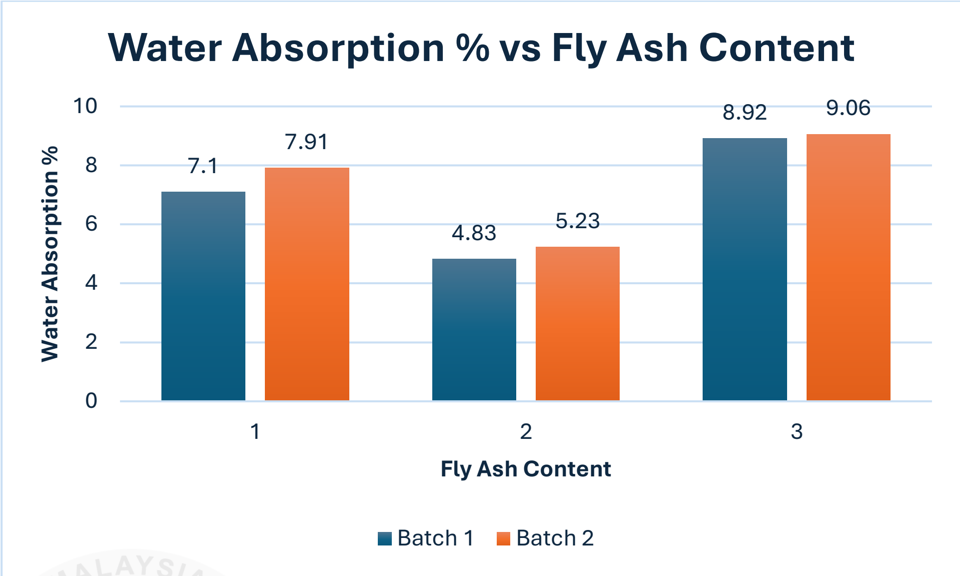


Figure 18: Water Absorption % vs Fly Ash Content

The water absorption test results of Batch 1 and Batch 2 show the difference in the absorption properties of different concrete mixes. From these, the water absorption percentage for Batch 1 ranged between 4.83 and 8.92%, while Batch 2 has given a higher range of absorption from 5.23 to 9.06%. The comparison among the various individual mixtures obviously shows the impact of different components included in Batch 2. For example, in Batch 2, the FA 10 + Add mix showed 7.91% against 7.10% recorded by Batch 1 FA 10 mix. Similarly, while Batch 1 had an absorption of 8.92% for FA 50, that of FA 50 + Add stood at 9.06% in Batch 2. There was even a marginal rise from 4.83% to 5.23% for FA 20 and FA 25 + Add.

These supplementary materials in Batch 2 may have affected the pore structure of the concrete matrix, contributing to slightly higher water absorption. Additions may alter the microstructure, which would increase the permeation of water. This tendency could also have been due to variations in material composition, in this case, the fly ash fraction. Also, the results might have been influenced by water curing, since this might have altered the hydration process, which, again, could have modified the absorption of water. Overall, the results show a slight increase in permeability due to changes effected in Batch 2, which perhaps needs further investigation regarding its effect on the durability of concrete.

4.5 Slump Test

Table 14 shows the slump test results of concretes obtained for different mix proportions. In fact, this slump test is required to obtain indications on workability and consistency in fresh state concrete, and each one reflects certain properties that are of direct interest in the process of placement and compaction. Indeed, it is possible to verify from slump values recorded in diverse mix designs and how modifications of material composition will alter its fluidity-cohesive balance. The results obtained give useful information on the suitability of each mix for a particular application in construction to ensure optimal performance and durability. In this experimental work, the slump test is done to the mixture of few mixing proportions with FA.

Table 14: Result of Slump Test

CONCRETE MIX	FINE AGGREGATES REPLACEMENT (%)	SLUMP (MM)
FA 10	10	**25**
FA 20	20	**33**
FA 50	50	**57**
FA 10 + ADD	10	**30**
FA 25 + ADD	25	**37**
FA 50 + ADD	**50**	**61**

It can be seen from Table 14 above; fresh properties result from all replacement. The mix proportion ratio produced high slump when the proportion is getting bigger. It also shows that the value of slump for FA10 is lowest compared to other proportion. This may be due to aggregate-to-aggregate friction from particles' irregular form and rough texture. FA10 can be concluded as the suitable proportion for workability since the value of slump is in the range with the grade of M25 even though it has a slight decrement to 25mm. With the increase of FA content shown in Figure 19, slump value increases. Maybe it indicates that the concrete has more water inside, which means high porosity. The higher the content of water, the higher the water-cement ratio, which has a negative influence on the total strength.

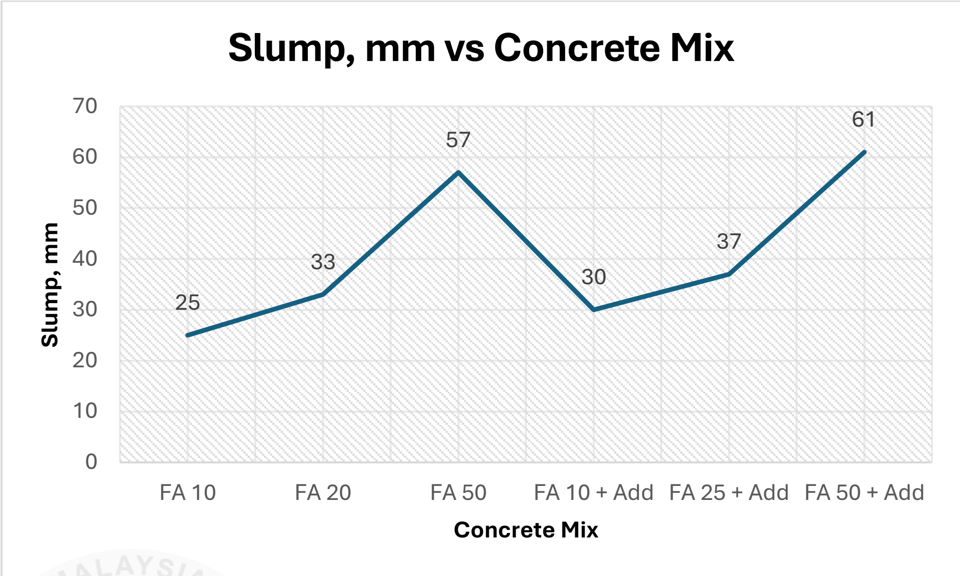


Figure 19: Result of Slump Test

There are a few things that contribute to the invalid result of the slump test. Insufficient rodding can result in adequate compacting and over rodding can cause segregation. Both will provide unreliable outcomes. Taking out slump cone can be highly important, and a sudden twist or jerk can greatly reduce the accuracy of results. Another important thing, the base where slump test is to be performed shall be level and vibration-free. Finally, never tamp the concrete mixture using steel rod with square end such a piece of rebar. This can force the large aggregates to the bottom of cone, thus make the test result invalid.

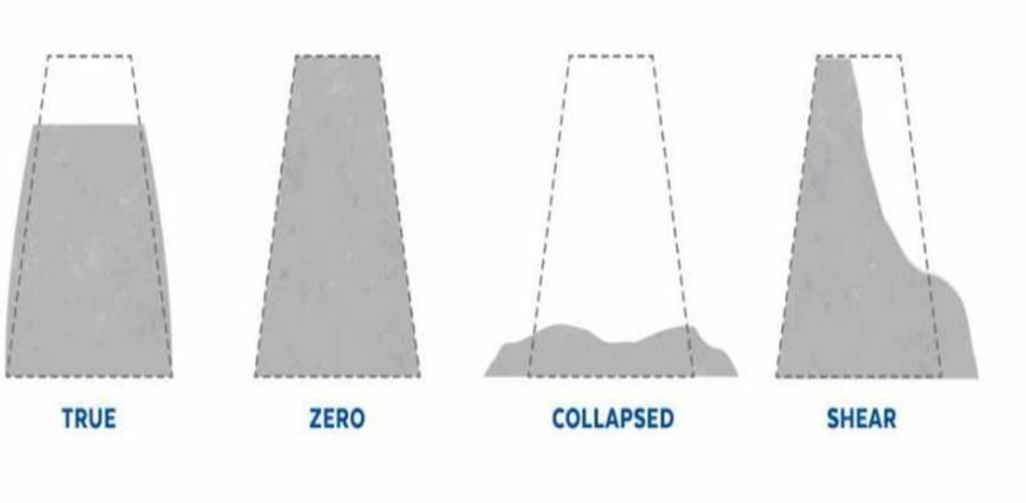


Figure 20: Possible Result of Slump Test

Figure 20 shows the possible result can be obtained for slump test. The concrete slump can be classified to four types which are true slump, zero slump, shear slump and collapse slump. In this experimental study, the result of true slump must be achieved. True slump will interpret that mixing of proportion is cohesive and most desirable. For other types of slump- zero, collapsed, shear-it must be avoided because it is inappropriate to use for making concrete. The strength also will be less than the true slump.

4.6 Compressive Test Result

This section presents the results and discussion of the compressive strength test, a method for determining axial load-carrying capacity, durability, and performance of concrete. In fact, the compressive strength is dependent on many factors: mix proportions, curing conditions, and aggregate properties, among others. This discussion reviews the results for the study of strength development and the identification of key factors that could possibly affect the performance of concrete.

Table 15: Compressive Strength (MPa) for Each Proportion

NO.	BATCH	MIXING PROPORTION	COMPRESSIVE STRENGTH (MPA)	TYPES OF DEFECTS
1	1	FA 10	11.5	Vertical Cracking
2		FA 20	8.6	Vertical Cracking
3		FA 50	2.9	Vertical Cracking
4	2	FA 10 + Additives	8.4	Vertical Cracking
5		FA 25 + Additives	5.9	Vertical Cracking
6		FA 50 + Additives	2.8	Vertical Cracking

The results follow a pattern in compressive strength under different FA proportions and with additional additions. It indicates that the higher the FA content is, the lower the compressive strength. For instance, FA 10 has the highest compressive strength value of 11.5 MPa while FA 20 and FA 50 resulted in lower compressive strengths with values of 8.6 MPa and 2.9 MPa respectively.

Compressive strength also decreases with the addition of additives. The strength of FA 10 + Additives is 8.4 MPa, which is lower than that of FA 10 without additives. FA 50 + Additives has the lowest strength at 2.8 MPa, while FA 25 + Additives has the highest strength at 5.9 MPa.

Figure 21: Type A Defect on Concrete Sample

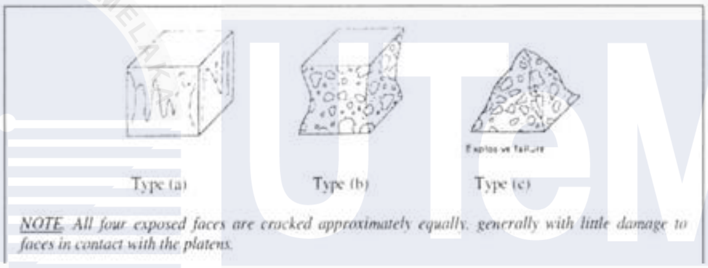


Figure 22: Type of Defects for Cube Sample

In the Figure 21, it clearly shows the effect of compression test (Vertical Cracking). This mode of failure is characterized by a vertical crack running along the height of concrete when axial compressive stress exceeds the tensile strength limits of concrete. The crack appears uniformly across all faces, indicating that the sample was well-mixed and properly compacted. It appears that the concrete failed due to compression without crushing except for 50 percent sample. This type of failure is considered satisfactory in compression testing.

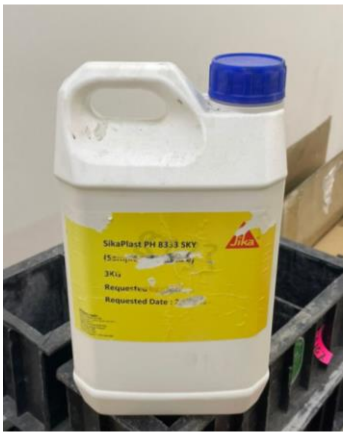


Figure 23: SikaPlast PH 8333 SKY Superplasticizer

There are a series of reasons in relation to which the mix containing SikaPlast PH 8333 SKY superplasticizer together with $CaCl_2$ presents lower compressive strength compared to the mix containing medical waste fly ash only. Overdosing on superplasticizer can be one cause, as the excessive dosage causes the excess dispersion of the cement particles. Superplasticizers are to enhance workability, but an excess amount of such substances weakens the cohesion among the particles, making the structure more porous and eventually low in compressive strength.

Besides, the interaction of the PCE-based superplasticizer with $CaCl_2$ might have caused lower strength. Calcium chloride is an accelerator that accelerates the rate of hydration. However, this might be counteracted upon the use of a PCE-based superplasticizer since the latter acts to increase dispersion and delay flocculation. This might result in quicker initial setting but poor long-term strength development because hydration may become non-uniform.

Analysis Results

Set	Analysis Parameter	Parameter Test	Method	SL Limit	Result	Unit
1	As	Arsenic		5.0 mg/l	<0.01	MGL
1	B	Boron		400 mg/l	<0.5	MGL
1	Cd	Cadmium	APHA 3500-Cd B	1.0 mg/l	<0.05	MGL
1	Cu	Copper	APHA 3500-Cu B	100 mg/l	0.2	MGL
1	Digestion	Digestion	APHA 3030E		NA	
1	Pb	Lead	APHA 3500-Pb B	5.0 mg/l	9.0	MGL
1	Ni	Nickel	APHA 3500-Ni B	100 mg/l	<0.1	MGL
1	O&G	Oil and Grease	APHA 5520 E (mod.)	1000 mg/kg	958	MGK
1	pH-E	pH after TCLP extraction	USEPA 1311		9.78	
1	pH-S	pH of slurry before TCLP extraction	USEPA 1311	> 5.5	10.4	
1	Cr	Total Chromium	APHA 3500-Cr B	5.0 mg/l	0.44	MGL
1	TOC	Total Organic Carbon		10 %	4.33	%
1	TS	Total Solids (105 C)			91.9	%
1	Zn	Zinc	APHA 3500-Zn B	100 mg/l	2.0	MGL

Figure 24: The Result of Fly Ash Content

As shown in Figure 24, The fly ash used in this research cannot contribute to the binding effect, which is required for the strength development due to the absence of calcium. However, the performance of the mix can still be influenced by other factors such as particle shape, fineness, or chemical composition. Since calcium does not participate in the pozzolanic reaction of gaining strength, the absence of it in fly ash could yield to lower compressive strength.

These combined effects may explain the higher compressive strength of the fly ash-only mix, since the superplasticizer and $CaCl_2$ did not interfere with a more stable pozzolanic reaction over time. It would be interesting to rework the dosages of superplasticizer and accelerator or run further compatibility tests to ensure a balanced hydration process for the optimization of the mixture.

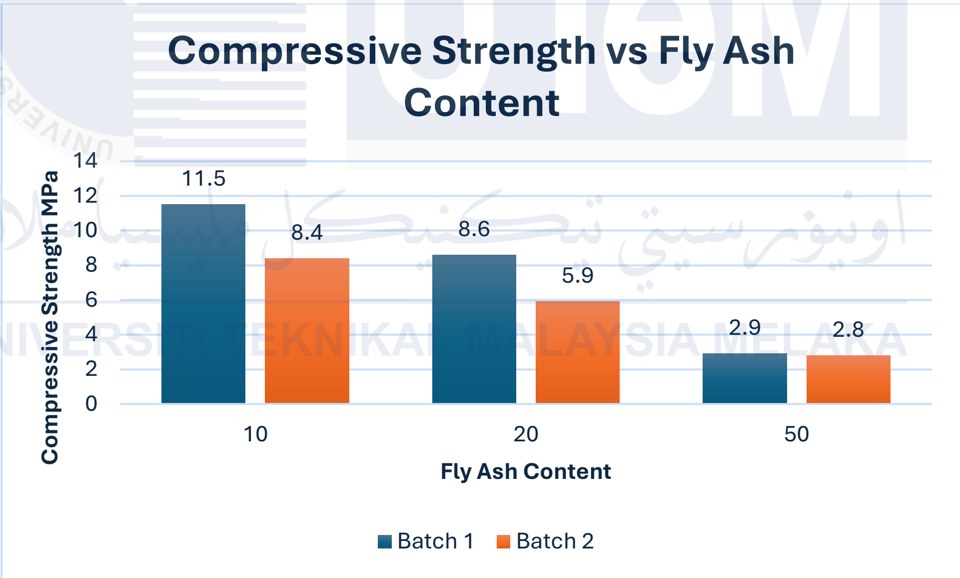


Figure 25: Comparison of Compressive Strength for Batch 1 and Batch 2

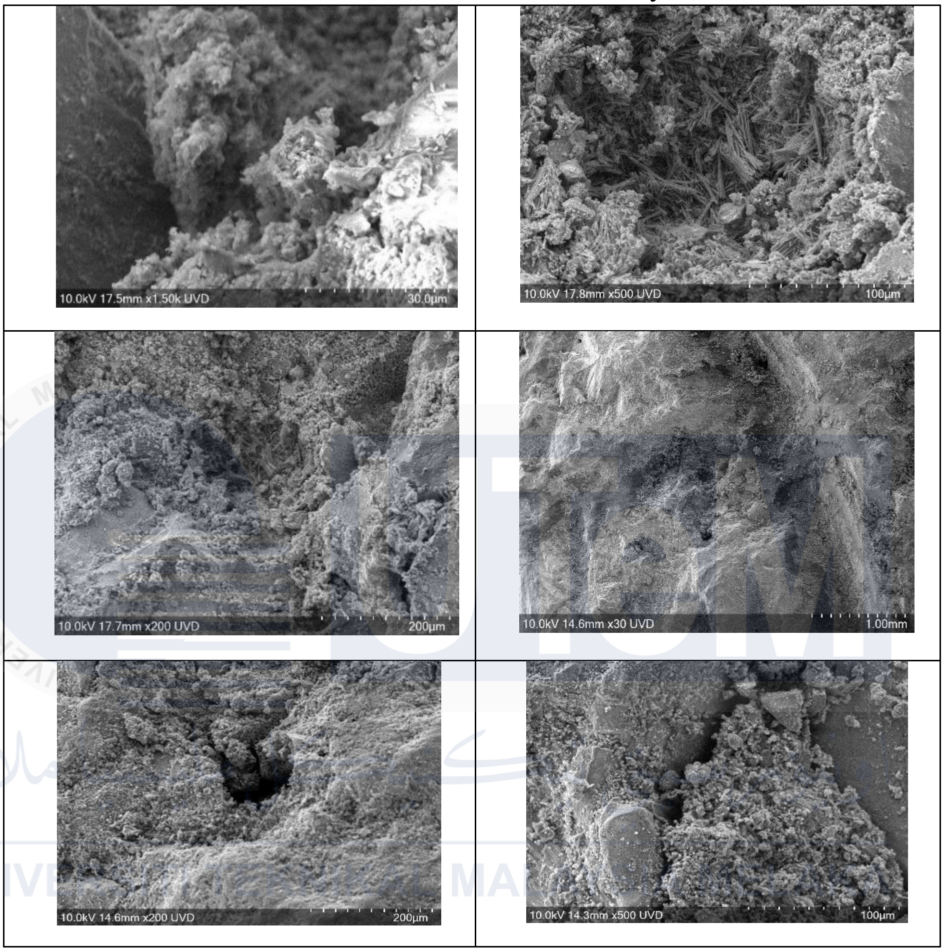
As observed from the above figure, considering the huge difference between the two samples, Batch 1 outperforms Batch 2. However, at a 50% replacement level, the difference is just 0.1, indicating a little variation. This infers that 50% of the fly ash percentage is not optimum since strength decreases as the proportion of fly ash increases.

4.7 Fe-SEM Result

This section presents the results and discussions of the examination using FE-SEM. The FE-SEM examines the microstructural properties, surface morphology, and elemental content of the concrete samples.

This method allows high-resolution imaging that can show hydration products, pore distribution, and the interfacial interaction between aggregates and the cement matrix in detail. The discussion of material mechanical performance and durability is made via analysis. The microstructural features which were realized on the concrete specimens by FE-SEM imaging are discussed below.

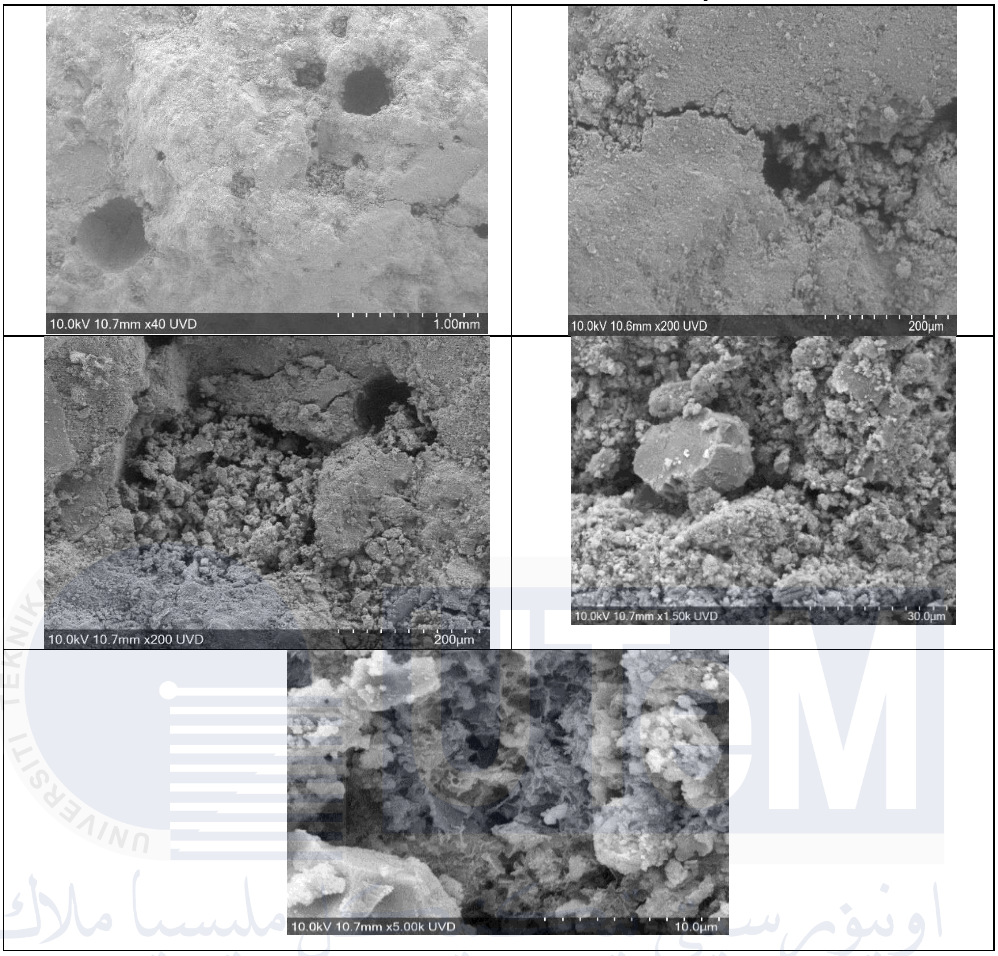
Table 16: Fe-SEM Result for 10 Percent Fly Ash Batch 1



The image represents a reasonably compact microstructure where fine, well-distributed fly ash particles are seen inside the cement matrix. The relatively small fly ash content, 10%, ensures effectiveness in the pozzolanic reaction with calcium hydroxide produced by the hydration of cement to produce extra calcium silicate hydrate gel, improving the bonding and filling up the voids within the matrix. The presence of fewer unreacted fly ash particles and a well-compacted structure suggests that at this level of fly ash replacement, the concrete has better strength and durability.

At 10% replacement, the fly ash is acting primarily as an additional cementitious material and does not cause a great disturbance in the hydration process. Particle size and morphology are beneficial in particle packing, with a resulting reduction in porosity and improvement in strength. Such a microstructure starts to form in the first days to weeks of hydration when the fly ash particles react with calcium hydroxide produced during the primary hydration of cement.

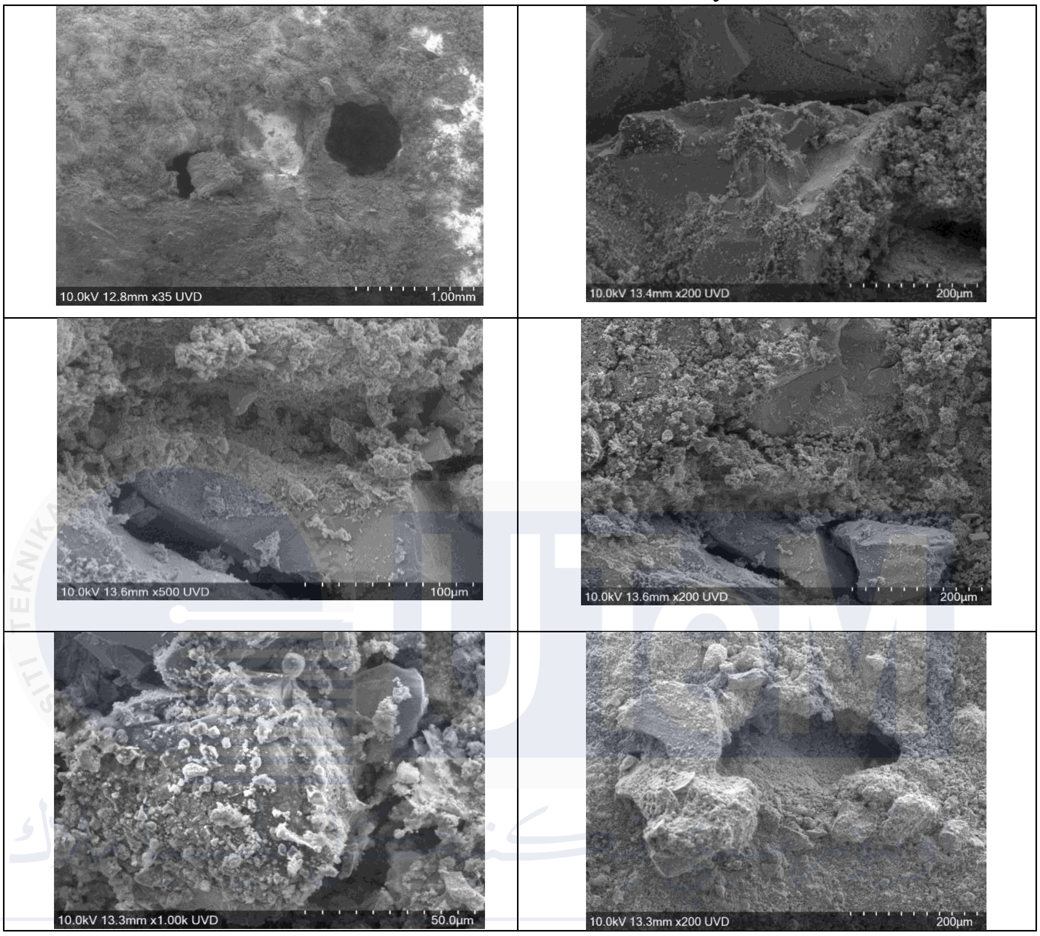
Table 17: Fe-SEM Result for 20 Percent Fly Ash Batch 1



This table depicts a much more porous and heterogeneous structure compared to those of the lower percentages. There are considerable numbers of unreacted fly ash particles, and voids and gaps appear in most areas of the matrix. The cementitious material is not as dense, thus meaning it would possess lower compressive strength. The reduced amount of cement restricts the amount of calcium hydroxide that can be produced, which is necessary for the pozzolanic reaction to continue efficiently.

At a 20% replacement, the balance between hydration and pozzolanic reactions begins to shift. While the spherical shape and pozzolanic activity of fly ash provide microstructural benefits, the higher percentage reduces the immediate availability of cement for hydration. This leads to slight increases in porosity. This stage typically occurs during the ongoing hydration and pozzolanic reactions, which become more evident after 7 to 28 days. This is because fly ash reacts more slowly than cement, causing the effects to become more noticeable over time.

Table 18: Fe-SEM Result for 50 Percent Fly Ash Batch 1



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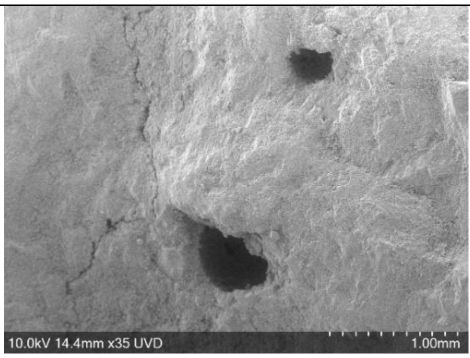
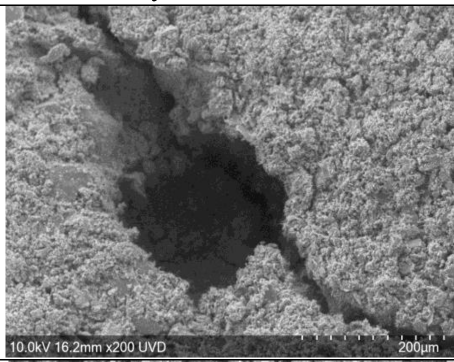
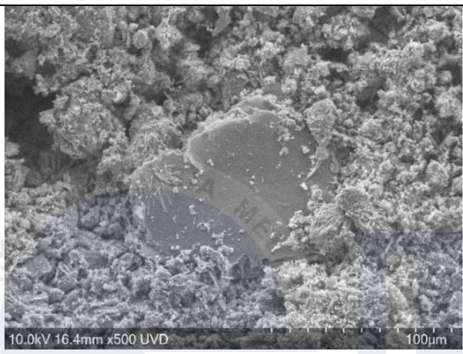
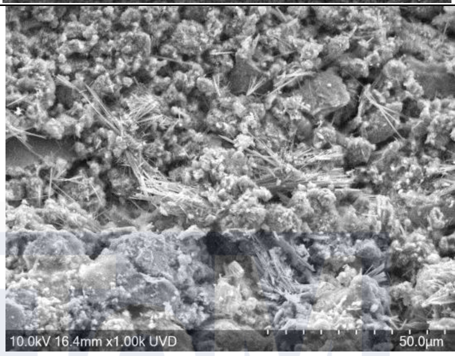
As in the case of 50% replacement, the amount of fly ash content is beyond the optimum level where the substitution may not be effective. The fly ash particles continue to engage in the pozzolanic reaction; however, with decreased cement content, the primary hydration becomes insufficient to support it. Consequently, incomplete bonding and hence increased porosity occur. Such microstructural changes usually happen in the initial days of curing-roughly between 7 to 28 days-and remain so for a long period because some unreacted fly ash particles are still present in the matrix.

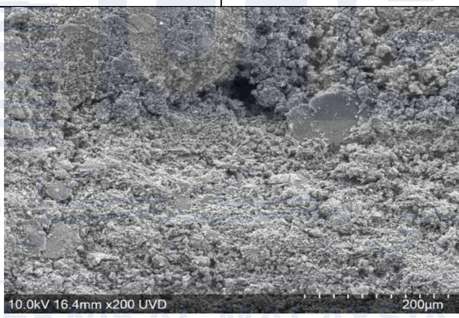
Table 19: Fe-SEM Result for 10 Percent Fly Ash Batch 2







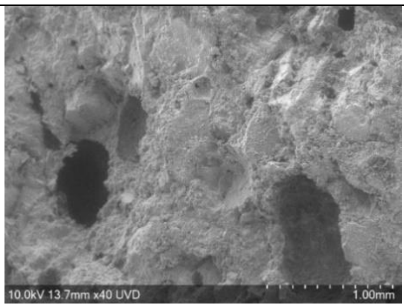
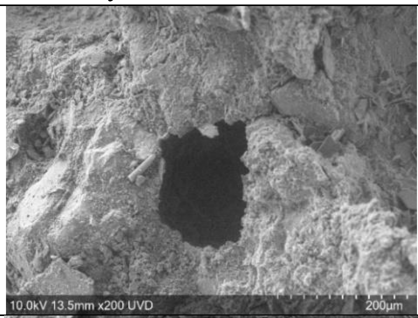
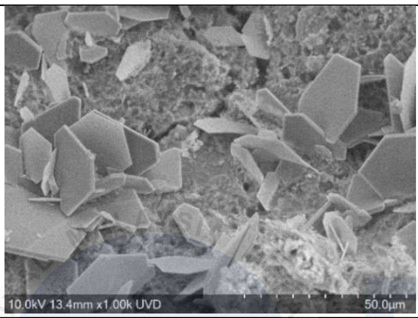
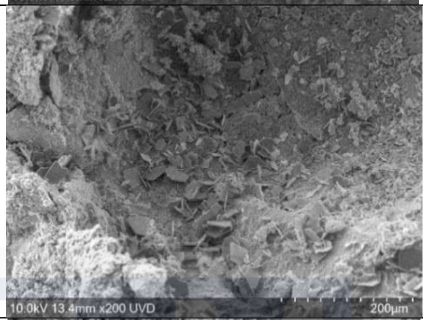
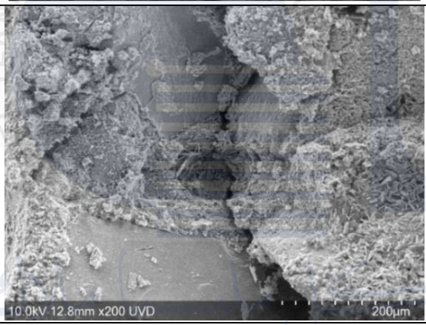




It has a dense microstructure with fewer voids, yet it maintains an analogy with the case of FA 10, showing very remarkable improvements concerning the bonding of the particles. This addition seems to accelerate hydration and to favor better particle dispersion thus there is a more homogeneous formation of the C-S-H gel in this kind of structure, which shows fewer unreacted particles when compared with conventional 10% fly ash replacement.

While calcium chloride accelerates the hydration processes and hence gives way to faster pozzolanic reaction rates, plasticizers improve workability by disaggregating the particles, promoting a better particle packing and thus decreasing porosity. For this reason, improved material properties develop during the early stages of curing-a period usually lying between the first 1 to 7 days-caused by the acceleration of the reactions with these additives.

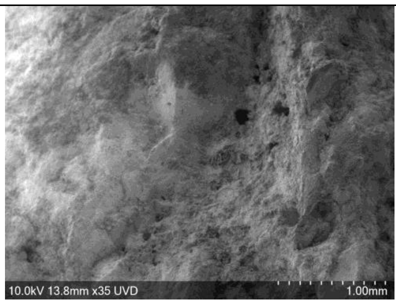
Table 20: Fe-SEM Result for 25 Percent Fly Ash Batch 2

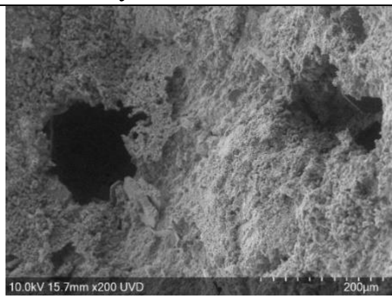
	
	
	

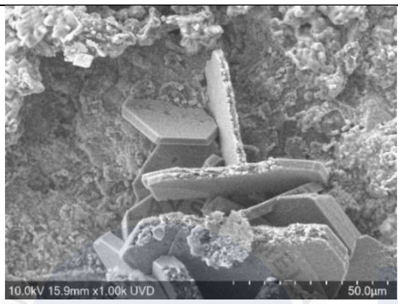
Microstructural analysis of the specimen made with 25% replacement of fly ash indicated a moderately dense cementitious matrix with a higher porosity compared to the one with 20% fly ash. The higher percentage of fly ash, along with additives, contributed to more unreacted particles and slightly reduced density. Additives improve workability and accelerate hydration; therefore, this partially compensated for the reduction of cement content by the improvement of hydration and pozzolanic reactions in the early stages. However, much higher reliance on pozzolanic reaction for strength development is imposed in this specimen because the early hydration contribution from the cement content is limited by its reduction. Some negative effects are improved by additives, and they cannot counterbalance the loss in strength due to reduction of cement content.

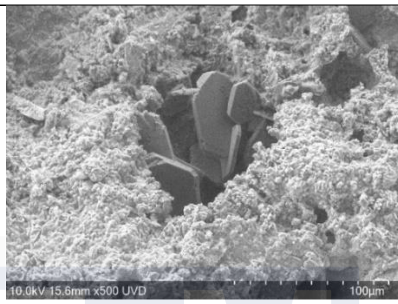
Most importantly, flake-like structures not observed in the previous 20% fly ash replacement sample start to appear in this sample. The flake-like structures result from increased fly ash content whereby the unreacted fly ash particles support the formation of secondary products during the pozzolanic reaction. These flakes point to the existence of on-going reaction processes within the matrix and indicate slower but continuous strength and hydration product development beyond early curing stages.

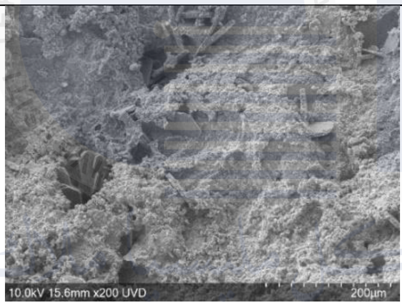
Table 21: Fe-SEM Result for 50 Percent Fly Ash Batch 2

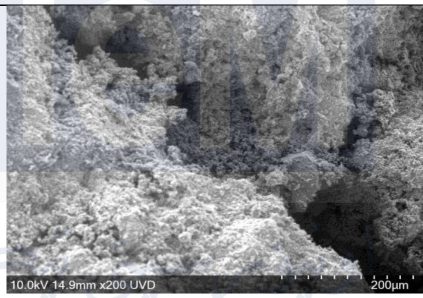












The flake-like structures develop further in the 50% fly ash replacement sample. A larger number of unreacted particles due to higher fly ash content increases the porosity and develops a less compact matrix. These flakes are primarily attributed to the pozzolanic reaction, which becomes more aggressive with increased silica from the fly ash reacting with calcium hydroxide that is a product of hydration. The high proportion of fly ash limits the availability of calcium hydroxide, reducing the reaction rates and hence a matrix that develops strength much more gradually.

In this sample, increased porosity and unreacted fly ash further compromise the density and mechanical properties, which additives cannot replace for such a large reduction in cement content. The abundance of flakes within the 50% fly ash sample testifies to the great change in hydration and strength development mechanism, with the pozzolanic activity already playing a dominant role, yet is insufficient to provide performance close to those at lower fly ash replacement percentages. This observation represents the challenge associated with finding an optimal balance between sustainability and performance at high fly ash replacement percentages.

Summary for Fe-SEM Analysis

Fe-SEM images of the influence of increased fly ash and the action of additives on the microstructure of concrete. Increasing FA alters the porosity, bonding, and density due to changes induced in hydration and pozzolanic processes. The balance required is understood from the point that additives will help but not completely overcome excessive FA.

FA 10% concrete is characterized by a dense structure with good bonding. Addition of 50% FA leads to a weak matrix due to high porosity developed by unreacted FA and voids. The balance of FA is hence important for sustaining strength and performance. Thicker C-S-H phases developed in lower FA levels enhance durability. Higher FA may lead to deterioration of concrete over time, as it may form needle-like ettringite, flaky calcium hydroxide, and inadequate hydration.

Performance optimization will always require a design in water-to-cement ratio, FA concentration, and curing modification. These methods enhance durability and integrity by reducing unwanted structures and promoting strong C-S-H. Hydration produces the beneficial to a limited extent, but in excess expansive and crack-inducing, needle-like ettringite. Mix management becomes very important because pozzolanic reaction of FA influences this.

Chemical admixtures such as plasticisers and calcium chloride act to improve FA-based concrete by reducing porosity and enhancing C-S-H. SEM pictures illustrate that treated mixes, such as 25% FA with $CaCl_2$, have a finer structure, improving sustainability. These conclusions are also supported by visual analysis. Concrete tends to be denser at 10% FA but flaky and needle like at 50% FA + Additives.

The key findings are porosity indicators, which indicate poor mechanical performance, needle-like ettringite, which affects durability and flaky calcium hydroxide, which is weak in bonding. FA is a green substitute, but too much of it depletes hydration. For long-term durability, mix design, curing, and additives should be done rightly. Future studies are needed to hone curing methods and additive utilisation to increase sustainable concrete.

4.8 EDX Result

The Energy Dispersive X-ray Spectroscopy results are shown in the following section. Energy dispersive X-ray is a physical-analytical technique called EDX that can determine the elemental composition needed to provide the necessary information on material overall properties and hydration products' chemical composition from concrete samples. Therefore, this study provides explanations about the composition and distribution inside the matrix if elements of calcium, silicon, and oxygen have been noted.

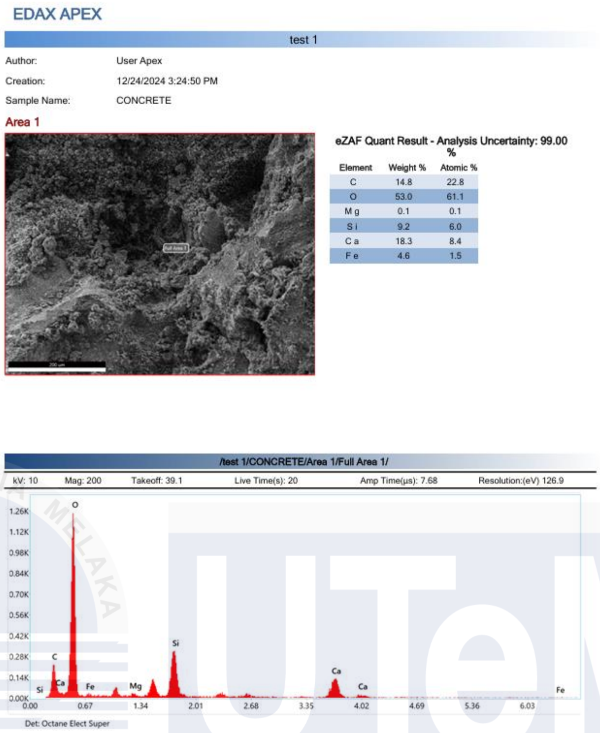


Figure 26: EDX Analysis Result for 10 Percent Fly Ash Batch 1

Analysed at 10 kV, with a magnification of 200x, a takeoff angle of 39.1°, and with a resolution of 126.9 eV, there are major constituents contributing to the material's structural integrity. The major elements that have been recorded in the scan area are a combination, but the richest is oxygen at 53.0 wt% and 61.1 at%; it confirms the presence of different oxides such as calcium oxide (CaO), silicon dioxide (SiO_2), and iron oxides (Fe_2O_3). These oxides play an important role in cementitious properties, improving strength and durability.

The other major component is calcium, which constitutes 18.3% by weight and 8.4% atomic, mainly in the form of calcium silicate hydrates, calcium hydroxide $Ca(OH)_2$, and calcium carbonate ($CaCO_3$); it acts as an binder in concrete and thus provides stability to the structure. It is also highly composed of carbon at 14.8% weight and 22.8% atomic, probably due to carbonation. Carbonation is a process by which atmospheric CO_2 reacts with calcium hydroxide to form calcium carbonate, affecting the porosity and long-term durability of the material.

Carbon may also originate from organic additives or environmental exposure. Silicon constitutes 9.2% by weight and 6.0% atomic and is part of silicate phases that go directly to mechanical strength in concrete. Iron exists as a trace, being 4.6% in weight and 1.5% atomic, probably because of iron oxide, corrosion of reinforcements, or impurities in the raw material. Iron can point toward degradation of the steel reinforcement, hence being at the very foundation for an assessment of durability.

Magnesium (0.1% weight, 0.1% atomic) can be detected only in trace quantities and might relate to the presence of magnesium silicates or even dolomite CaMg $(CO_3)_2$, but this does not contribute much to the average composition.

These observations are further confirmed by the EDS spectrum that also shows major peaks at ~0.67 keV corresponding to oxygen, ~0.28 keV corresponding to carbon, ~1.6 keV corresponding to silicon, and ~3.65 keV and ~4.02 keV corresponding to calcium. Smaller peaks corresponding to ~6.03 keV for iron and ~1.2 keV for magnesium point towards their minor contribution. From the above results, it is observed that the sample has a general cementitious composition and may contain carbonation effects, hence with probable reinforcement corrosion risks.

EDAX APEX

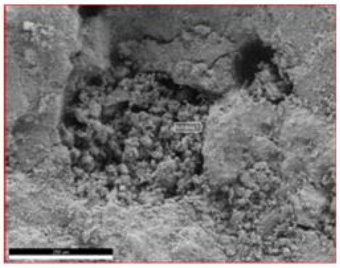
test 1

Author: User Apex

Creation: 12/24/2024 3:31:04 PM

Sample Name: CONCRETE

Area 2



eZAF Quant Result - Analysis Uncertainty: 99.00 %

Element	Weight %	Atomic %
C	19.5	31.0
O	42.4	50.4
Mg	0.6	0.5
Si	8.3	5.6
Ca	19.4	9.2
Fe	9.8	3.3

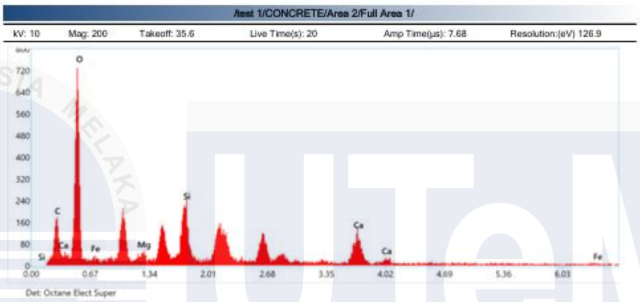


Figure 27: EDX Analysis Result for 20 Percent Fly Ash Batch 1

These were made at 10 kV, x 200, TOA 35.6° and Resolution 126.9 eV respectively. The following analysis depicts main components existing within the material's structure. The scanned area indicates the presence of a mix of all the essential elements; hence, oxygen (weight 42.4%, atomic 50.4%) is most in abundance to form oxides with other metals: calcium oxide, CaO; silicon dioxide, SiO_2; and iron oxides, Fe_2O_3. These oxides have key roles to play in cementitious properties, mainly in strength and durability.

Calcium is a major component of the sample at 19.4% weight and 9.2% atomic, to form hydration products such as C-S-H, $Ca(OH)_2$, and $CaCO_3$. These are important in the setting and hardening of concrete. There is also a large proportion of carbon present at 19.4% weight and 9.2% atomic, indicating carbonation-a chemical reaction whereby atmospheric CO_2 reacts with calcium hydroxide to maybe form calcium carbonate. It may affect porosity, density, and the long-term durability of the material. Besides, carbon may also come from organic additives or environmental exposure.

The second main element is silicon, which exists at 8.3% by weight and 5.6% by atom, playing a basic role in the conformation of silicate phases, improving the mechanical properties of concrete. Iron was found in higher proportions than what would be expected: 9.8% by weight and 3.3% atomic. This may indicate reinforcement corrosion contamination from raw materials or iron-based additives. A higher iron content may also point out embedded steel reinforcements whose corrosion might have some repercussions on structural integrity. Magnesium was detected in small amounts (0.6 wt%, 0.5 at%) and is probably linked to magnesium silicates or to the mineral dolomite, $CaMg(CO_3)_2$, both of which could affect the concrete microstructure and its behaviour.

The EDS spectrum further supports this observation, with prominent peaks at ~0.67 keV for oxygen, ~0.28 keV for carbon, ~1.74 keV for silicon, and ~3.35 keV and ~4.02keV for calcium. Further minor peaks at ~6.03 keV for iron and ~1.34 keV for magnesium confirm their minor but relevant presence. Overall, this analysis indicates that the concrete sample follows a standard cementitious composition but exhibits a relatively high carbon and iron content. This could imply exposure to carbonation effects and potential reinforcement corrosion risks, which are critical factors in assessing the material's durability and long-term performance.

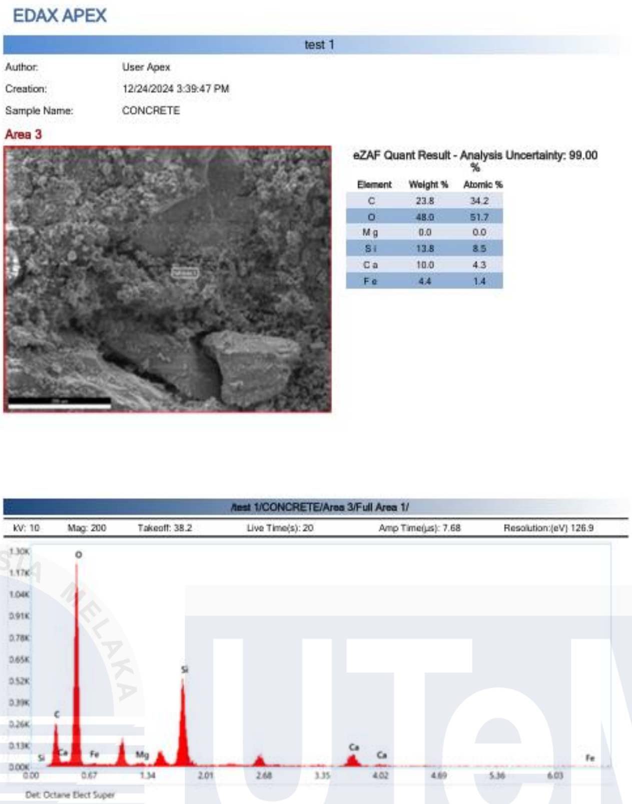


Figure 28: EDX Analysis Result for 50 Percent Fly Ash Batch 1

This was carried out at 10 kV, with a magnification of 205x, a takeoff angle of 37.6°, and a resolution of 126.9 eV. The main components affecting the performance of the material are seen in the analysis. The major constituent is oxygen, making up 53.7% of the weight and 63.6% of the atomic composition. This high value of oxygen suggests that many oxides might be present in the constitution of the material, such as calcium oxide (CaO), silicon dioxide (SiO_2), and aluminium oxides (Al_2O_3), which will contribute much toward strength and durability. These oxides are very essential in cement chemistry, particularly where hydration reactions and strength development of the product are involved.

Another major constituent is calcium, forming 22.3% by weight and 10.6% by atomic composition. The most important cementitious compounds are calcium silicate hydrates (C-S-H), calcium hydroxide $Ca(OH)_2$, and calcium carbonate $CaCO_3$. Calcium acts as the binder that holds the concrete together, giving strength and stability to the material. In more ways than one, calcium makes possible the binding compounds that give concrete its strength.

Carbon is also present in appreciable amounts, making up 10.6% by weight and 16.8% in atomic percentage. This may be the result of carbonation, a natural process whereby carbon dioxide from the air reacts with calcium hydroxide in the concrete to form calcium carbonate. Although this sometimes brings an increase in surface strength, excessive carbonation may reduce alkalinity, and thus potentially make the concrete more vulnerable to reinforcement corrosion over time. This process can change the porosity of the concrete, reducing alkalinity and possibly affecting reinforcement corrosion resistance.

Silicon, necessary for the formation of silicate phases, contributes much to mechanical strength: 7.0% weight, 4.7% atomic. Aluminium at 3.8% weight, 2.7% atomic may indicate the presence of alumina-based compounds like calcium aluminate phases, which contribute to good early strength gain and resistance to sulphate attack. Sodium at 0.8% weight, 0.7% atomic is in lesser quantities and may relate to alkali-silica reactions (ASR) at the expense of durability.

Moreover, there are minor traces of sulphur (0.9% weight, 0.6% atomic) and chlorine (0.8% weight, 0.4% atomic), which prove the presence of sulphates and chlorides that can lead to long-term deterioration by chemical reactions, causing expansion and cracking. The EDS spectrum corresponding to this verifies these findings, with strong peaks at ~0.67 keV for oxygen, ~0.28 keV for carbon, ~1.74 keV for silicon, and ~3.35 keV and ~4.02 keV for calcium. Smaller peaks at around 1.49 keV for aluminium, 1.04 keV for sodium, 2.3 keV for sulphur, and 2.62 keV for chlorine confirm their minor contributions.

In general, the analysis shows that this concrete sample is well balanced in composition with the necessary cementitious elements. However, carbonation effects, potential alkali-silica reaction risks, and minor sulphate and chloride content point to environmental influences that may affect durability over time. These findings are very important for the evaluation of long-term performance and resistance of the material under different exposure conditions.

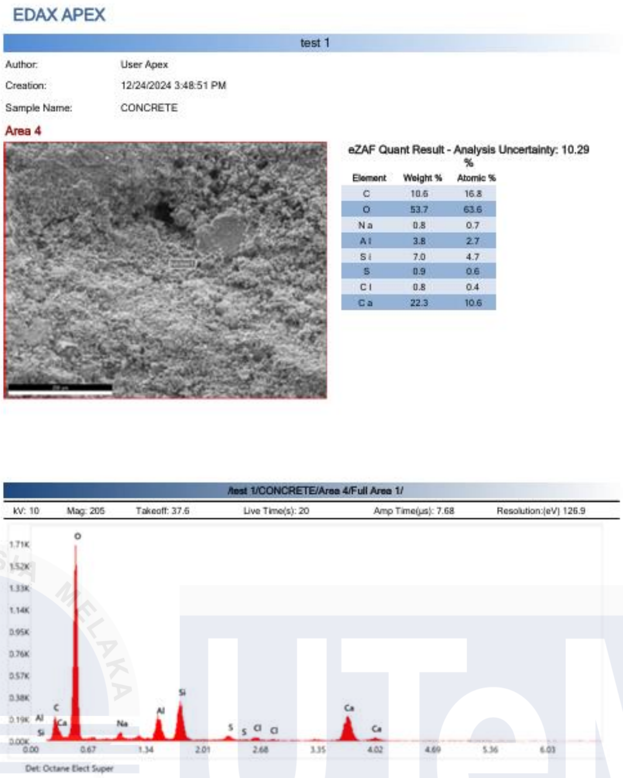


Figure 29: EDX Analysis Result for 10 Percent Fly Ash Batch 2

The analyses were carried out at 10 kV, magnification 205x, takeoff angle 37.6°, and resolution 126.9 eV, allowing the major elements contributing to the performance of the material to be identified. Most abundant is oxygen (53.7 weight percent; 63.6 atomic percent), which represents a variety of oxides, such as calcium oxide (CaO), silicon dioxide (SiO_2), and aluminium oxides (Al_2O_3). All these oxides are very important in the chemistry of cement because they affect hydration reactions and development of strength.

The other major constituent is calcium, making up 22.3% by weight and 10.6% atomic, which is important in the formation of cementitious compounds: calcium silicate hydrates (C-S-H), calcium hydroxide ($Ca(OH)_2$), and calcium carbonate ($CaCO_3$). Calcium confirms the binding properties of the concrete for durability and stability. Also present in appreciable amount (10.6% weight, 16.8% atomic) is carbon, likely due to carbonation—that is, the reaction of atmospheric CO_2 with calcium hydroxide to form calcium carbonate, which may change the porosity of concrete and reduce its alkalinity, likely affecting the corrosion resistance of reinforcement.

Silicon at 7.0 wt% and 4.7 at% is core to the formation of silicate phases, contributing much to mechanical strength. The content of aluminium 3.8% weight and 2.7% atomic indicates the presence of alumina-based compounds, such as calcium aluminate phases, which encourage early strength gain and enhance sulphate attack resistance. Sodium is in small quantities, 0.8% weight and 0.7% atomic, and, hence, it could also be related to alkali-silica reactions (ASR), potentially affecting durability.

In addition, there are traces of sulphur and chlorine amounting to 0.9% weight, 0.6% atomic and 0.8% weight, 0.4% atomic respectively, which are indicative of sulphates and chlorides that may have potential consequences on long-term durability by facilitating chemical reactions promoting expansion and cracking. The corresponding EDS spectrum confirms these results by showing considerable peaks at about 0.67 keV for oxygen, 0.28 keV for carbon, 1.74 keV for silicon and 3.35 and 4.02 keV for calcium. Smaller peaks at approximately 1.49 keV for aluminium, approximately 1.04 keV for sodium, approximately 2.3 keV for sulphur, and approximately 2.62 keV for chlorine affirm their secondary roles.

In general, the analysis shows that this concrete sample is well balanced in composition and contains all the main cementitious elements. However, the effects of carbonation, potential alkali-silica reaction risks, and minor contents of sulphate and chloride point out environmental influences that may affect durability over time. These results are very important for the determination of long-term performance and resistance of the material under different exposure conditions.

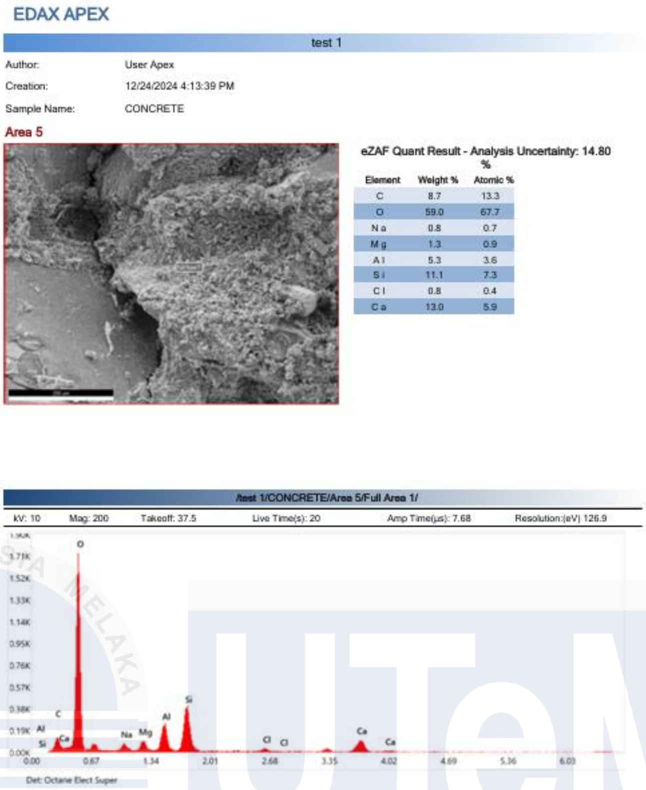


Figure 30: EDX Analysis Result for 25 Percent Fly Ash Batch 2

EDX analysis on this sample of concrete is outlined below, giving a complete understanding of the elemental composition and to that end structural and chemical properties. 10 kV, 200x magnification, 37.5° takeoff angle, and resolution 126.9 eV - this has become indicative of key elements which contribute to material integrity. The percentage composition by weight of oxygen is 59.0% and is 67.7% atomic. This could indicate that there are several oxides, such as CaO, SiO_2, and Al_2O_3. These oxides are the basis for cement chemistry, as they dominate hydration reactions and the improvement in strength and durability of the material.

The major component of this is calcium at 13.0% by weight and 5.9% atomic, forming the critical cementitious phases of calcium silicate hydrates, C-S-H, and calcium hydroxide, $Ca(OH)_2$, which provide binding in construction. Carbon, 8.7% by weight and 13.3% atomic, would indicate carbonation effects involving the reaction of atmospheric CO_2 with calcium hydroxide to produce calcium carbonate, $CaCO_3$. Carbonation effects could have an influence on porosity, long-term durability, and possibly resistance to reinforcement corrosion.

Other key components include silicon at 11.1% by weight and 7.3% atomic, related mainly to silicate phases giving mechanical strength to the concrete. In the same regard, aluminium at 5.3% by weight and 3.6% atomic is indicative of alumina compounds, which are helpful in early strength gain and sulphate resistance. The presence of sodium was 0.8% by weight and 0.7% atomic; magnesium, on the other hand, was 1.3% by weight and 0.9% atomic, probably related to ASR and dolomite ($CaMg(CO_3)_2$). Their structure contribution is very low, but perhaps long-term durability may be influenced.

Also, 0.8% weight or 0.4% atomic chlorine is present, which might indicate exposure to chloride contamination probably causing corrosion of embedded steel reinforcement. This fact is confirmed through the EDX spectrum that corresponds to the major peaks at ~0.67 keV for oxygen, ~0.28 keV for carbon, ~1.47 keV for silicon, and ~3.35 keV and ~4.02 keV for calcium. Small peaks, around 1.49 keV for aluminium, 1.04 keV for sodium, 1.2 keV for magnesium, and 2.68 keV for chlorine, support their presence in trace amounts.

These test results, in general, provide evidence that the concrete sample includes a normal cementitious composition, major elements responsible for strength and durability. Nevertheless, carbonation, a possible risk of alkali-silica reaction, and minor chloride content may show evidence of environmental effects on long-term performance and durability. Knowledge of these chemical interactions is very important in trying to assess the resiliency and sustainability of this material over time.

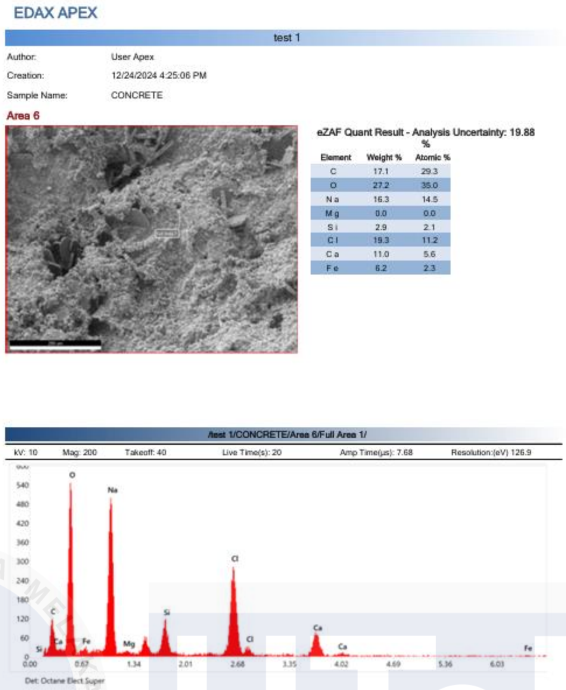


Figure 31: EDX Analysis Result for 50 Percent Fly Ash Batch 2

The EDX analysis of Area 6 in the concrete sample gives comprehensive data on elemental composition helpful in the understanding of the chemical characteristics. This was done at 10 kV, with a magnification of 200x, a takeoff angle of 40°, and a resolution of 126.9 eV. In its turn, the scanned area presents a quite complex combination of elements, in which oxygen with 27.2 wt% and 35.0 at% is dominant. It surely points to the existence of such oxides as CaO, SiO_2, Na_2O, and Fe_2O_3.

The oxides of those elements are of crucial importance for the manifestation of the cementitious properties: they form strong and durable matrices of concretes. A large percentage of sodium at 16.3% weight and 14.5% atomic indicates contamination with salt exposure, probably from accelerators and water reducers-CaCl-that might have a related influence on concrete degradation through alkali-silica reaction.

Carbon is also present in large quantity, at 17.1% by weight and 29.3% by atomic percent, probably due to carbonation-a process in which atmospheric CO_2 reacts with $Ca(OH)_2$ to form $CaCO_3$-and may be expected to affect the long-term durability of the material. The presence of chlorine (19.3% weight, 11.2% atomic) is particularly important; it might show possible chloride ingress, leading to reinforcement corrosion in case steel reinforcements are embedded in the concrete.

Calcium, being 11.0% by weight and 5.6% atomic, is still a fundamental constituent in concrete through the formation of C-S-H and calcium hydroxide, among others, which imparts mechanical properties to concrete. Silicon is found to be present in the form of 2.9% weight and 2.1% atomic to support silicate phases, contributing to strength. Iron is given to a moderate amount at 6.2% wt. and 2.3% atom. It can originate from iron oxide, reinforcing corrosion, or raw materials impurities.

EDX spectrum with significant peaks at about 0.67, 1.04, 2.68, 3.74, and 4.02 and 6.03 keV corresponding to oxygen, sodium, chlorine, calcium, and iron, respectively, confirms this observation. These sodium and chlorine peaks were quite strong and reflected the possible action of an aggressive environment like sea water or chloride-laden atmospheres on the specimen that was expected to cause acceleration in the deterioration process. These findings indicate that the concrete specimen has been subjected to some kind of chemical attack, which could compromise its long-term durability and structural integrity.

Comparison of EDX Analysis Data

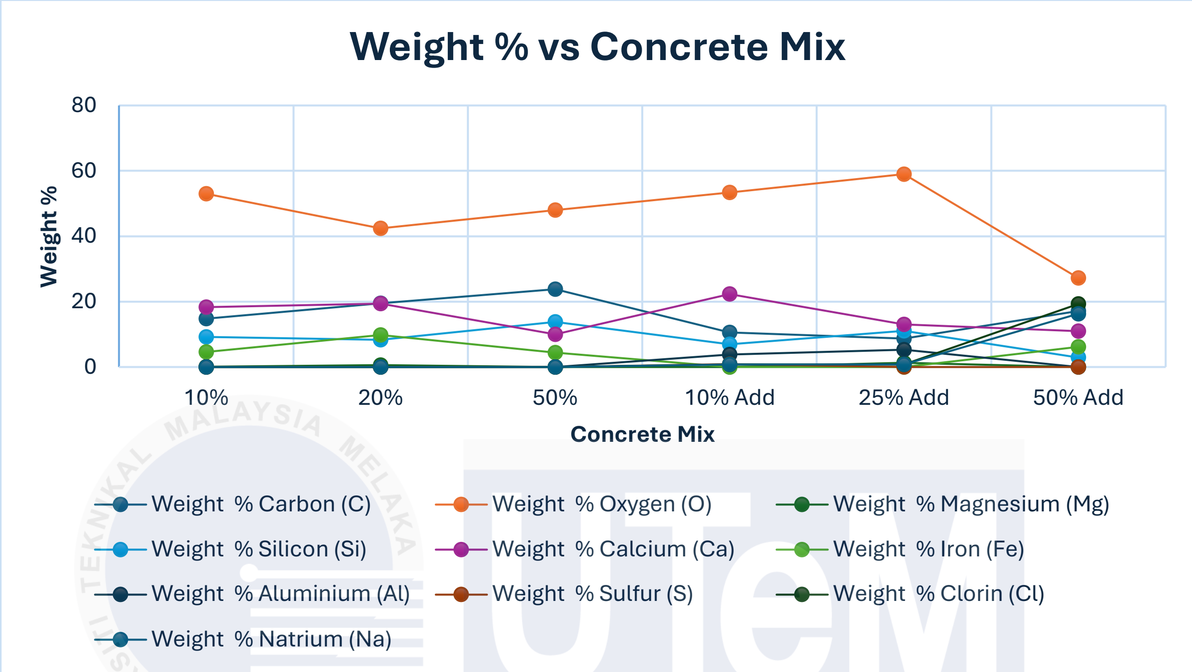


Figure 32: Weight % vs Concrete Mix

This graph represents six different fly ash concretes, by elemental composition, focusing on elements such as oxygen, carbon, silicon, calcium, and iron. Oxygen is the most predominant and constitutes 40-60%, mainly contributed by oxides CaO, SiO_2, Al_2O_3, and Fe_2O_3, which form the cementitious matrix.

Carbon levels are different, showing unburnt fly ash that could have possible effects on workability and resistance to freeze-thaw action. Silicon (5-15%) ensures adequate pozzolanic reaction; calcium (10-20%) supports hydration and strength. The variation in calcium shows different replacement levels of fly ash, as higher the fly ash, the lower the calcium content.

Iron (5-10%) influences setting time but very minimal structural effects. Aluminium (3-6%) helps in early strength and reduces permeability. Sodium and chloride, however, pose risks like ASR and steel reinforcement corrosion. Sulphur (0.5-1%) in higher amounts may indicate sulphate contamination, risking expansion and concrete deterioration.

Generally, this graph confirms key oxides necessary for concrete performance but points out those that must be controlled chloride and sulphate to avoid any damage to structures. Proper mix design together with appropriate material selection is critical for ensuring long-term durability of fly ash concrete.

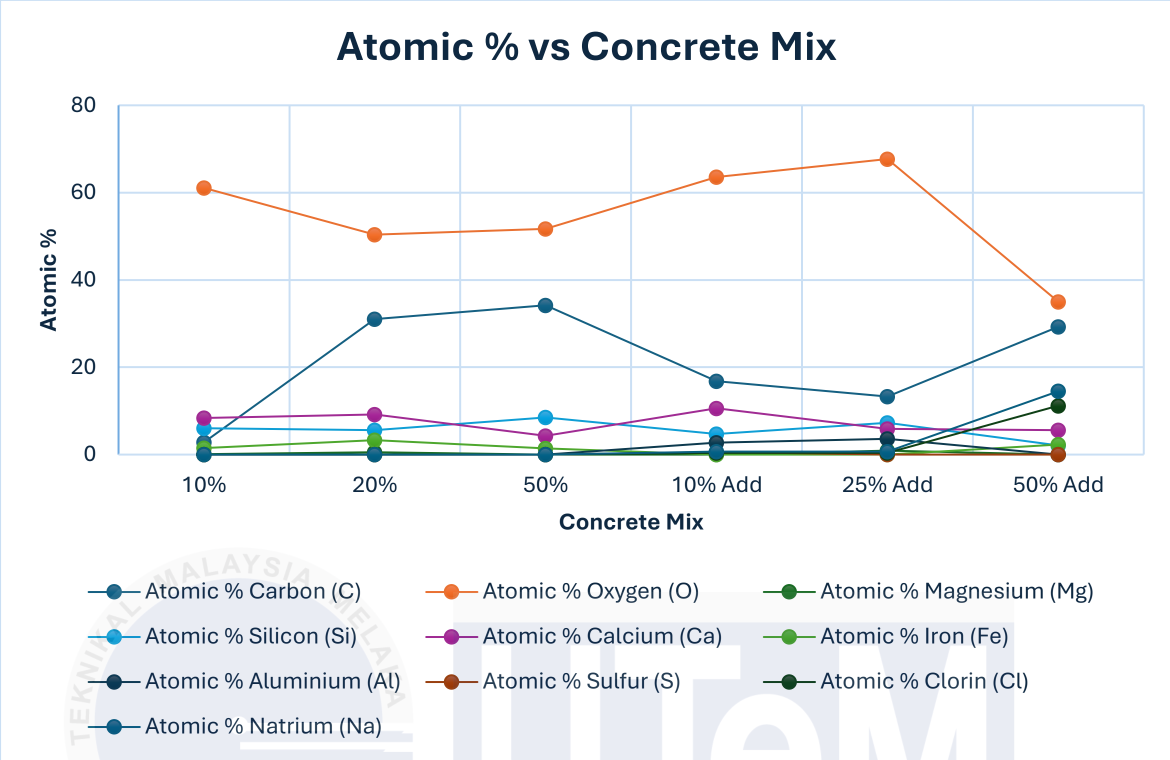


Figure 33: Atomic % vs Concrete Mix

Atomic percentage of the elements in the fly ash concrete samples from the graph. The x-axis represents the number of samples, and the y-axis represents atomic percentage of elements. The key elements are C, O, Mg, Si, Ca, Fe, Al, S, Cl, and Na.

High oxygen levels would indicate oxides important for hydration and durability. Variations in oxygen suggest differences in hydration and environmental exposure. The high carbon in samples 2, 3, and 6 could be due to unburned fly ash or carbonation, which affects strength and porosity. Calcium and silicon contents are critical to cement hydration and strength. Differing calcium contents indicate variability in hydration and/or possible leaching; a stable silicon content supports continuing pozzolanic reactions and resistance in the long term.

The relatively high sodium and chlorine contents could reflect chloride exposure, with a risk of reinforcement corrosion; alternatively, these elements may be from chemical admixtures. Although present in lesser quantities, Fe, Al, Mg and S have also some influences on the concrete properties. Magnesium could potentially affect expansion and durability, but normally Fe and Al originate from impurities in raw materials. Sulphur, usually present in sulphate form, may lead to sulphate attack.

CHAPTER 5

SUMMARY

5.1 Conclusion

This paper outlines an investigation into the compressive strength, water absorption, and density along with the microstructural features in concretes made with FA replacement and with the addition of additives. In the test results, 10% FA replacement showed the maximum compressive strength, which was 11.5 MPa, while higher FA contents of 20% and 50% caused a significant reduction in the strength due to high porosity and the presence of unreacted particles. While additives improved workability and hydration, they contributed to reduced compressive strength, probably because of overdosing or incompatibility with FA. Water absorption results showed a slight increase for mixtures containing additives, between 7.91% and 9.06%, as compared to mixtures without additives, ranging between 4.83% and 8.92%, which may indicate an alteration of the pore structure of the concrete.

The slump values given in this paper showed that with higher replacement levels of FA and the addition of additives, the density of the concrete decreased. The highest recorded density was 2154.16 kg/m³ at 20% FA replacement, while the lowest recorded was 1885.99 kg/m³ for 50% FA with additives. The microstructural study indicated that the lower percentage of FA developed a denser and more compact C-S-H structure, yielding better strength and durability, while higher levels of FA lead to a porous matrix with unreacted particles, reflecting poor structural performance. EDX further identified the possibility of carbonation, chloride ingress, and alkali-silica reaction in mixes, especially those either with higher FA content or with additives that could potentially affect long-term durability.

In general, the investigation showed that 10% FA replacement is optimal in balancing strength, durability, and sustainability. Similarly, FA replacement above ≥50% had an adverse effect on mechanical and durability properties, and the use of additives requires cautious dosage and compatibility assessment to ensure performance optimization. Future research should be directed at mix design improvement, refining curing methods, and exploring advanced additive formulations for enhanced sustainability-performance in FA-based concrete.

5.2 Recommendation for Future Study

More detailed research and optimization are advisable for an improved performance of FA-based concrete. Mix design adjustments may be made to investigate other FA replacement levels-intermediate, such as 15% or 30% and water-cement ratio and additive dosage adjustments could yield an improved balance between strength and sustainability. Also, the selection of additives must be tried by doing a mix that contains single additives to see the effect of additives without mixing few additives into one mix. This can help in selecting the best additives to be used that will come out the best for concrete strength, durability, and good in morphological structure.

Further work should also be done to study alternative curing techniques, including steam curing or extended curing periods, for possible improvement in long-term durability. FA reactions can be further improved in efficiency by the incorporation of supplementary cementitious materials such as silica fume and GGBS. Long-term performance tests like sulphate resistance, chloride penetration, and freeze-thaw cycle tests need to be conducted to find out the actual durability of FA concrete.

From an environmental and economic point of view, such FA coming from medical waste could be used for concrete production based on a quantification of the environmental benefit through a life cycle assessment. The cost-benefit analysis will be valuable regarding the usage of FA concretes when compared with conventional mixtures. Other microstructural interactions, including superplasticizers and accelerators other than those available for minimum deleterious effects in FA-added concrete, must be pursued. Advanced characterization techniques such as X-ray diffraction and thermogravimetric analysis might provide more valuable insight into the hydration phases and the reaction mechanisms.

REFERENCES

A study on environmental impact from construction operation in residential areas / Mohamad Khairul Nizam Abdul Ghani and Emma Marinie Ahmad Zawawi - UiTM Institutional Repository. (n.d.). https://ir.uitm.edu.my/id/eprint/47788/

American Concrete Institute (ACI). "Guide to the Use of Fly Ash in Concrete." ACI Committee 232.

Birchard, K. (2002). Out of sight, out of mind...the medical waste problem. *The Lancet, 359*(9300), 56. https://doi.org/10.1016/S0140-6736(02)07256-2

Chang, A. C., Lund, L. J., Page, A. L., & Warneke, J. E. (1977). Physical properties of Fly Ash-Amended soils. *Journal of Environmental Quality*, *6*(3), 267–270. https://doi.org/10.2134/jeq1977.00472425000600030007x

Concrete vs Cement: What's The Difference? | Howden. (n.d.). https://www.howden.com/en us/articles/cement/how-is-cement made#:~:text=To%20make%20concrete%20a%20mixture,an%20impenetrable%20rock%2Dlike%20mass.

Gebler, S. H., & Klieger, P. (1986). Effect of fly ash on physical properties of concrete. In *Special publication - Royal Society of Chemistry/Special publication* (Vol. 91, pp. 1–50). https://doi.org/10.14359/10063

Gielen, D., Boshell, F., Saygin, D., Bazilian, M., Wagner, N., & Gorini, R. (2019, April 1). The role of renewable energy in the global energy transformation. Energy Strategy Reviews. https://doi.org/10.1016/j.esr.2019.01.006

Helmuth, R. (1987). "Fly Ash in Cement and Concrete." Portland Cement Association.

Hernandez, M., Scarr, S., & Daigle, K. (2021, February 18). The messy business of sand mining explained. *Reuters*. https://www.reuters.com/graphics/GLOBAL-ENVIRONMENT/SAND/ygdpzekyavw/

Jena, B. (2021). Impact of improper biomedical waste disposal on human health and environment during COVID-19 pandemic. European Journal of Molecular and Clinical Medicine; 8(3)4137-4143, 2021.

K.K. Padmanabhan, Debabrata Barik (9 Nov 2018). Health Hazard of Medical Waste and its Disposal, Energy from Toxic Organic Waste for Heat and Power Generation. https://doi.org/10.1016%2FB978-0-08-102528-4.00008-0

Kaur, H., Siddique, R., & Rajor, A. (2019, November 1). Influence of incinerated biomedical waste ash on the properties of concrete. Construction and Building Materials. https://doi.org/10.1016/j.conbuildmat.2019.07.239

Manekar, S. S., Bakal, R. L., Jawarkar, R. D., & Charde, M. S. (2022). Challenges and measures during management of mounting biomedical waste in COVID-19 pandemic: an Indian approach. *Bulletin of the National Research Centre/Bulletin of the National Research Center*, *46*(1). https://doi.org/10.1186/s42269-022-00847-4

Manimaran, R., Jayakumar, I., Giyahudeen, R. M., & Narayanan, L. (2018). Mechanical properties of fly ash composites—A review. *Energy Sources Part a Recovery Utilization and Environmental Effects*, *40*(8), 887–893. https://doi.org/10.1080/15567036.2018.1463319

Ng, N. (2020, May 6). Clinical waste in Malaysia has risen 27% since MCO. How are we getting rid of it? CILISOS - Current Issues Tambah Pedas! https://cilisos.my/heres-howmalaysia-deals-with-clinical-waste-thats-increased-since-the-pandemic/

Opon, J., & Henry, M. (2019). An indicator framework for quantifying the sustainability of concrete materials from the perspectives of global sustainable development. *Journal of Cleaner Production, 218,* [No page numbers provided]. https://doi.org/10.1016/j.jclepro.2019.01.220

Padmanabhan, K. K., & Barik, D. (2019). Health hazards of medical waste and its disposal. In *Energy from Toxic Organic Waste for Heat and Power Generation* (pp. 99–118). Elsevier. https://doi.org/10.1016/B978-0-08-102528-4.00008-0

Razali, S. S., & Ishak, M. B. (2010, December 31). Clinical waste handling and obstacles in Malaysia. Journal of Urban and Environmental Engineering. https://doi.org/10.4090/juee.2010.v4n2.047054

Thomas, M. D. A., & Matthews, J. D. (1992). Carbonation of fly ash concrete. *Magazine of Concrete Research*, *44*(160), 217–228. https://doi.org/10.1680/macr.1992.44.160.217

Yi, T. C., & Jusoh, M. N. H. (2023). *Overview of clinical waste management in Malaysia*. https://www.akademiabaru.com/submit/index.php/fwe/article/view/3810

Zhang, H., Shi, X., & Wang, Q. (2018). Effect of curing condition on compressive strength of fly ash geopolymer concrete. *ACI Materials Journal*, *115*(2). https://doi.org/10.14359/51701124

APPENDIX