REPUBLIC OF RWANDA

ULK POLYTECHNIC INSTITUTE

P.O Box 2280 Kigali

Website: //www.ulkpolytechnic.ac.rw

E-mail: polytechnic.institute@ulk.ac.rw

ACADEMIC YEAR 2023/2024

DEPARTMENT OF CIVIL ENGINEERING

OPTION OF CONSTRUCTION TECHNOLOGY

TECHNICAL STUDY ON THE USE OF FLY ASH AS COMPLEMENT OF CEMENT IN CONCRETE

CASE STUDY: RWANDA

Submitted in partial Fulfilment of the requirements for the award of Advanced diploma in Construction technology

Presented by: Deborah UMWALI

Roll Number :202150544

Under the Guidance of: **Eng. Bonaventure NKIRANUYE**

Kigali, October 2024

DECLARATION

I, Deborah UMWALI (202150544), student at the ULK Polytechnic Institute, Civil Engineering Department, option of Construction Technology, hereby declare that this report of "**Technical study on the use of fly ash as complement of cement in concrete in Rwanda**" project, done and checked under the supervision of Eng. **Bonaventure NKIRANUYE,** is my original work and has never been submitted anywhere for any academic qualifications.

Signature………………

Deborah UMWALI

Date…/…/……

CERTIFICATE

This research project entitled "**Technical study on the use of fly ash as complement of cement in concrete prepared"** by UMWALI Deborah in partial fulfilment of the requirements for award of advanced diploma (A1) in civil engineering /construction technology has been examined and approved by

Supervisor: Eng. Bonaventure NKIRANUYE

Date: …. /……../2024

Signature………..

Head of department

Eng. Bonaventure NKIRANUYE

Date…/…. /2024

Signature…………

DEDICATION

This Report is dedicated to the following persons who without them the project could not be successfully completed, materially, intellectually, physically and financially contributed to make the project success. Firstly, the Almighty God who enables in our studies, our dearest parents who encourage and support us in all our studies, our beloved brothers, sisters and relatives, our friends and colleagues, all our Lectures and ULK Polytechnic Institute management who provided good environment to work in, and finally especially our supervisor Eng. Bonavanture NKIRANUYE, who guides us a lot. You are the sun that lightens our lives, for you, we dedicate this work.

ACKNOWLEDGEMENT

Firstly, I would gladly like to thank the all department of civil engineering, the library for the support they rendered at all times, and the general community of ULK Polytechnic Institute that provided with me the knowledge through all these years. I also thank them for the workshops and field visit trips that were provided to us for further understanding of the learnt modules practically.

My deepest acknowledgement goes to my supervisor, Eng. Bonaventure NKIRANUYE, despite his multiple responsibilities, he accepted to supervise me during the period of this work. His helpful interventions, assistance and encouragements provided me to do well this work.

Also, I am highly grateful to my Lecturers, to my parents and relatives, to the college and classmates for their great support. Their knowledge and wisdom have supported and enlightened me throughout the process of my studies.

ABSTRACT

The construction industry is one of the main fields making up the worldwide development today and it is also developing fast similarly as in our country Rwanda. The use of concrete that has been commonly adapted in this development era in construction should suit the quality and economy. To achieve this, the materials to be used in construction is the main issue to be addressed. That brought us to think about the assessment use of locally available material, Peat-coal Fly Ash (PFA) that can be applied as complement of cement in concrete which does not yet have a perfect application. This project intends to reduce the cost of construction projects by taking into account the appropriate technology of maximizing the use of residue material. The project was carried out by doing various tests to get optimum PFA percentage to be used. The use of fly ash as complement of Ordinary Portland Cement (OPC) in concrete was evaluated. OPC was replaced with PFA by weight at 5%, 10%, 15% and 20%, where 0% PFA was used as a reference. Compressive strength test was carried out on 150mmx150mmx150mm steel mould after 3 days curing in a water bath. Although, the results revealed that the compressive strength of the hardened concrete increases as percentage of replacement with PFA increases, it was shown that optimum percentage of PFA is 10% of replacement corresponds with compressive strength of 18.053Mpa at 3 days. Slump test result showed with a partial replacement of cement by PFA that the increase in percentage PFA reduces the slump. But the amount of the water was kept the same W/C=0.5. At the 10% replacement of PFA the slump was 95mm, this complement is environmentally friendly and cost effective. It is advised that more research be done to learn more details regarding the suitability of partially replacing OPC with PFA in concrete.

Keywords: Concrete technology, peat coal fly ash, concrete compressive strength, slump, and concrete production economy.

TABLE OF CONTENTS

DECLARATION ... **ii**

CERTIFICATE ... **iii**

DEDICATION ... **iv**

ACKNOWLEDGEMENT ... **v**

ABSTRACT ... **vi**

TABLE OF CONTENTS ... **vii**

LIST OF TABLES ... **x**

LIST OF FIGURES ... **xi**

LIST OF ABBREVIATIONS ... **xii**

LIST OF APPENDICES ... **xiii**

CHAPTER ONE: GENERAL INTRODUCTION ... **1**

1.0. Introduction ... 1
1.1. Background and Rationale ... 1
1.2. Problem Statement ... 3
1.3. Research questions ... 4
1.4. Objectives of the study ... 4
1.4.1. Main objective ... 4
1.4.2. Specific objectives ... 4
1.5. Scope and Limitations ... 4
1.5.1. Scope ... 4
1.5.2. Limitations of the research ... 5
1.6. Significance of the study ... 6
1.6.1. Personal benefits ... 6
1.6.2. Academic benefits ... 6
1.6.3. Social-economic benefits ... 6
1.7. Organization of The Thesis ... 7

CHAPTER TWO: LITERATURE REVIEW ... **8**

2.0. Introduction ... 8
2.1. Building materials ... 8
2.1.1. Concrete ... 8

2.1.2. Composition of concrete 9
2.2. Conceptual review 10
2.2.1. Use of both cement and fly ash in construction 10
2.2.2. Use and contribution of cement versus fly ash to concrete structures 10
2.2.3. Relationship between fly ash and cement in concrete production 11
2.2.4. Standards application in construction 11
2.3. Theoretical review 12
2.3.1. Portland cement 12
2.3.2. Peat coal fly ash 16
2.4. Empirical review 27
2.4.1. Tests done on fresh concrete 27
2.4.2. Tests done on hard concrete 27
2.5. Gaps in current research 30
2.6. Future research directives 31
CHAPTER: MATERIALS AND METHODS 32
3.0. Chapter review 32
3.1. Description of Study Site 32
3.2. Research design 32
3.3. Materials 33
3.3.1. Fly ash 33
3.3.2. Cement 34
3.3.3. Fine Aggregates 34
3.3.4. Coarse Aggregate 35
3.3.5. Water 35
3.4. Tools and equipment used 35
3.4.1. Balance 36
3.4.2. Steel mould 36
3.4.3. Tamping rod 36
3.5. Methodology for collecting data 37
3.5.1. Preparation of testing specimens 37
3.5.2. Tests conducted 39
3.5.3. Interview 42
3.6. Data analysis and interpretation 42
3.6.1. Microsoft Excel 42
3.6.2. Google Earth .... **Error! Bookmark not defined.**
3.7. Consideration of Engineering ethics 42
CHAPTER FOUR: RESULTS AND DISCUSSIONS 43

4.0. Chapter overview 43
4.1. Specimen preparation and curing.. 43
4.2. Slump test.. 43
4.3. Casting concrete specimen... 45
4.4. Test of compressive strength 45
4.5. Pricing and cost estimation of concrete 47
CHAPTER 5. CONCLUSION AND RECOMMENDATIONS 49
5.1. Conclusion 49
5.2. Recommendations... 49
REFERENCES.. 50
APPENDICES 54

LIST OF TABLES

Table 2. 1: Classification of Portland cement 14
Table 2. 2: Cement chemical composition 15
Table 2. 3: Identification of different types of coal 18
Table 2. 4: Chemical composition of fly ash 23
Table 2. 5: The typical range of composition for fly ash made from several types of coal 24
Table 2. 6: hydration reaction of Portland cement and fly ash Portland cement 26
Table 2. 7: Concrete mix ratio based on concrete grade 30
Table 2. 8: Compressive strength of grades of concrete at 7 and 28 days 30
Table 3. 1: Mix Portion for different percentages of PFA 38
Table 4. 1: Slump of concrete mixtures 44
Table 4.2: Normal concrete compressive strength 45
Table 4.3: Concrete compressive strength with 5% replacement 45
Table 4.4: Concrete compressive strength with 10% replacement 45
Table 4.5: Concrete compressive strength with 15% replacement 46
Table 4.6: Concrete compressive strength with 20% replacement 46
Table 4.7: Comparison of compressive strength of all concrete grades 46

LIST OF FIGURES

Figure 2. 1: Portland cement bag 12
Figure 2. 2: Coal 16
Figure 2. 3: Conditioned fly ash to utilization or disposal 17
Figure 2. 4: Types of coal 18
Figure 2. 5: Use of fly ash in different dams 19
Figure 2. 6: Fly ash and cement 20
Figure 2. 7: Classes of fly ash 25
Figure 2. 8: Example of hardened concrete 28
Figure 2. 9: Concrete cubes specimens and compressive machine 29
Figure 3. 1: Rwanda location by Google Earth 32
Figure 3. 2: Research design phases 33
Figure 3. 3: Fly ash 34
Figure 3. 4: Twiga Cement of 42.5 34
Figure 3. 5: Kayumbu sand 35
Figure 3. 6: Coarse aggregate 35
Figure 3. 7: China electronic laboratory digital scale 600g – 0.5g 36
Figure 3. 8: Steel mould 36
Figure 3. 9: Tamping rod 37
Figure 3. 10: Picture of me during curing process 39
Figure 3. 11: Performing compressive strength test 40
Figure 3. 12: Slump Test of concrete 41
Figure 4. 1: Specimen boxes ready for test after curing 43
Figure 4. 2: Slump test graph 44
Figure 4. 3: Concrete compressive strength with varying % fly ash 47

LIST OF ABBREVIATIONS

ASTM: American Standard for Testing and Materials

BS: British Standard

FA: Fly Ash

GoR: Government of Rwanda

HT: High temperature

LOI: Loss On Ignition

LT: Low temperature

MININFRA: Ministry of Infrastructures

OPC: Ordinary Portland Cement

PA: Pond Ash

PCC: Portland Cement Concrete

PFA: Peat coal Fly Ash

PMs: Project Managers

REMA: Rwanda Environment Management Authority

UCS: Unconfined Compression Strength

ULK: Kigali Independent University

UNEP: United Nations Environmental Protection

WOPC: White Ordinary Portland Cement

%: Percentage

3D: Three Dimensions

LIST OF APPENDICES

Appendix 1) Measuring the ingredients that will be used to make concrete 55
Appendix 2) Proceeding with concrete setting time test..56
Appendix 3) Carrying out slump test...57

CHAPTER ONE: GENERAL INTRODUCTION

1.0. Introduction

This chapter summarize the background of study from worldwide situation to the study case area, the problem statement, the objectives of study, the significance of study, the scope and limitations of study, and the organization of all report chapters.

1.1.Background and Rationale

Worldwide, because of its advantages for the environment and the economy, using fly ash in place of some of the cement in concrete has attracted the biggest attention. Fly ash, a byproduct of burning coal, lowers the need for Portland cement, whose manufacture contributes significantly to carbon dioxide emissions. Many locales, especially wealthy nations like the United States, Europe, and some parts of Asia, add fly ash to concrete to improve durability, reduce permeability, and increase long-term strength. Additionally, in line with global efforts to reduce industrial waste and advance environmentally friendly building techniques, is the usage of fly ash (Rao, 2023).

Fly ash has been used by coal-producing nations like China and India to reduce waste management problems. Fly ash is easily accessible in these areas, and its application in the making of concrete has greatly lessened the environmental impact of cement production. Furthermore, fly ash is now a feasible substitute for cement in major infrastructure projects like highways, bridges, and dams due to the lower costs associated with doing so. These changes are indicative of a global trend toward more environmentally friendly building practices and waste management techniques.

Nonetheless, there are certain difficulties in using fly ash worldwide. Because of environmental concerns, there is a declining supply of high-quality fly ash in areas moving away from coal-based power generation. There is concern that there may be a fly ash scarcity as coal facilities close to make way for renewable energy sources, thereby increasing expenses. Notwithstanding these obstacles, there is a bright future for the use of fly ash, particularly as nations seek out novel approaches to fulfill their environmental obligations and lower the carbon footprint of building.

In Africa, in comparison to other areas, the use of fly ash from peat coal as a partial replacement for cement in the production of concrete has taken longer to catch on. One explanation is the continent's decreased reliance on coal for energy production, which reduces the quantity of fly ash available as a byproduct. Nonetheless, a number of African countries are starting to investigate its possibilities, particularly in view of the growing urbanization and the need for eco-friendly construction materials. Fly ash utilization in construction is being pioneered by nations with more developed coal industry, such as South Africa and Nigeria (Kassa et al., 2019).

Concrete containing fly ash is an opportunity as well as a challenge due to Africa's building boom. The need for cement is rising because of the quick growth of infrastructure in many areas, which raises Carbon dioxide (CO_2) emissions. Adoption of fly ash could encourage the usage of nearby resources while helping to mitigate this impact on the environment. A number of African nations have begun to look into joint ventures with global organizations in an effort to prioritize sustainable building methods, like the application of fly ash, in their development plans.

A major obstacle to fly ash's extensive use in Africa is the absence of a well-developed regulatory framework and a lack of knowledge among engineers and builders about its advantages. Governments and the building sector in Africa must fund research, establish guidelines for its application, and increase public knowledge of the benefits fly ash offers in terms of both the environment and the economy. Fly ash could play a major role in sustainable building solutions as more African nations pledge to lower their carbon emissions.

Rwanda offers a favorable environment for utilizing fly ash from peat coal to produce concrete because of its dedication to environmental preservation and sustainability. Government of Rwanda (GoR) doesn't have a sizable coal sector, but its commitment to green growth initiatives creates opportunities for the importation of fly ash and the investigation of substitute indigenous materials with pozzolanic qualities (MININFRA, 2022). Fly ash construction might lower cement use and support Rwanda's climate goals as the nation continues to prioritize infrastructure development, especially in homes, roads, and public areas.

The government of Rwanda has taken the initiative to develop laws that support sustainable lifestyles, like the Green Growth and Climate Resilience Strategy. The application of fly ash in the construction industry would aid in achieving these objectives by lowering the greenhouse gas emissions associated with the production of regular cement. Additionally, employing fly ash could reduce the overall cost of construction projects in Rwanda, which would make the development of infrastructure more accessible, especially for large-scale public projects like housing schemes, bridges, and highways.

There are still issues, though, like the restricted local fly ash supply and the requirement to acquire it from other nations that have coal businesses. Rwanda should concentrate on working with foreign organizations and other African countries to create a fly ash supply chain in order to make the shift feasible. Furthermore, increasing fly ash's usage in Rwanda's construction industry requires educating engineers and contractors about the advantages of doing so. Rwanda has the willingness to lead the East African area in sustainable construction if given the right policies and incentives (Kumar *et al.*, 2021).

1.2. Problem Statement

If fly ash accumulation is not well controlled, it can provide serious environmental risks. Since fine fly ash particles can become airborne during transportation, storage, or inappropriate disposal, air pollution is one of the main problems. Once in the atmosphere, these particles can aggravate illnesses like bronchitis and asthma and cause respiratory issues in both humans and animals. Fly ash poses health hazards, but it can also lower air quality by creating dust clouds that obstruct vision and contribute to particulate matter pollution, which is bad for the environment (Garg and Singh, 2024).

Contamination of water is another significant issue. Rainwater can contaminate surrounding water sources with hazardous heavy metals like lead, mercury, and arsenic when fly ash is dumped in landfills or large open ponds. This leaching can contaminate rivers, lakes, and groundwater, endangering aquatic life and rendering the water unfit for human consumption. Additionally, bioaccumulation of toxins in the food chain due to contaminated water sources can have a detrimental impact on ecosystems and possibly pose long-term health hazards to both humans and wildlife.

Fly ash buildup can result in land damage in addition to polluting air and water. Large tracts of land are usually needed for fly ash disposal, which disrupts natural ecosystems and changes the topography. Because fly ash is composed of a poor nutrient content, it can cause barren, infertile areas and render the land used for fly ash dumps unsuitable for cultivation or other useful uses. Furthermore, over time, fly ash storage sites may become unstable, which could result in disastrous events like the collapse of ash ponds or landfills and cause extensive environmental damage (Chu *et al.*, 2021).

The construction industry continuously grows around the world including Rwanda and the technologies have emerged to face various difficulties in the construction. The manufacturing cement companies are main contributor to release carbon dioxide in the environment. Approximately 0.9 ton of cement produced emit one ton of carbon dioxide and it is responsible for global warming added that about every year 1.89 billion cement-tons, which is a major component of concrete, has been manufactured around the world. Around 10% of total world carbon dioxide emission comes from the cement manufacturing process in cement factories.

Based on these statistical facts, there is need to conduct this study to examine whether if using fly ash can be successful, to protect the environment.

During the concrete manufacturing, cement is the expensive material which lead to the increase in its cost; according to this, our project needs to evaluate if utilizing peat coal ash can help in minimizing the cost and quantity of cement to be used in concrete.

1.3. Research questions

The questions that needed answers which will help the architects, engineers and project managers to understand the necessity and importance of using fly ash as a complement for cement during concrete manufacturing, were considered. Those questions include the following:

- ✓ What are the effects of different percentages of fly ash replacement on the compressive strength of concrete at different curing periods?
- ✓ What is the optimal fly ash-to-cement ratio that maximizes compressive strength without compromising workability?
- ✓ How does concrete that has fly ash mixed in impact the strength development compared to conventional Portland cement concrete?

1.4. Objectives of the study

1.4.1. Main objective

The main objective of the study is to evaluation the technical feasibility and performance of using fly ash as a supplementary material in cement for concrete production, aiming to improve sustainability, cost-effectiveness, and structural integrity in Rwanda.

1.4.2. Specific objectives

The specific objectives of the study can be subdivided into the following ones:

- ✓ Assess the compressive strength of concrete due to different percentages of fly ash used.
- ✓ Evaluate the durability and workability of concrete percentages differences of fly ash.
- ✓ Examine the cost differences when a quantity of fly ash is added as a complement of cement in concrete manufacturing.

1.5. Scope and Limitations

1.5.1. Scope

The study focuses on the use of peat coal fly ash as complement of cement in normal concrete as economic and environmentally friendly materials by conducting slump test and compressive strength test. However, it was advised for the split tensile test and cube density to be carried out to check the sustainability of using fly ash which are not part of scope.

1.5.2. Limitations of the research

The variation in the composition and quality of fly ash may be one of the main study constraints. As a byproduct of burning coal, fly ash's chemical makeup varies greatly according on the coal's source, the combustion process, and the collection techniques used. It could be challenging to make broad generalizations because of this diversity, which could also impact the consistency of the data. As a result, by gathering samples from various places and studying them independently, the study might need to take into consideration variances in fly ash qualities in Rwanda.

The lack of knowledge regarding the long-term performance of concrete that adds fly ash to the cement mixture is another possible drawback. Although fly ash can enhance the concrete's workability and durability, it may not be possible to fully understand the long-term impacts within the study's time range, such as potential delayed strength gain or changes in structural integrity over time. The durability and lifetime of fly ash-modified concrete must be evaluated over an extended period of time; however, this may be outside the purview of the study.

Fly ash concrete's mechanical and chemical properties can be better understood by laboratory testing, but real-world performance may vary (Punurai *et al.*, 2018). In contrast to controlled lab settings, field applications may subject the concrete to a variety of environmental elements, including loads, moisture, and temperature fluctuations, which may have an impact on how well it performs. The study's limited capacity to replicate a variety of field settings may limit its conclusions regarding fly ash's applicability in larger construction projects.

Fly ash usage in concrete is governed by laws and construction codes, which can change depending on the location. Certain locations may have limitations on the fly ash's quantity that can be added to concrete or require adherence to particular testing procedures. The study's conclusions may not be as applicable in other areas or sectors due to these regulatory obstacles. Inconsistencies may also arise when comparing the outcomes of various research because there are no established testing procedures for fly ash concrete.

Fly ash can lessen the need for cement, which helps the environment be more sustainable, but there may still be worries about the material's own environmental effects. Concrete waste including fly ash could contaminate land or water if it is handled or disposed of improperly. Fly ash can include trace levels of heavy metals. The study may not adequately address these environmental hazards, especially if it ignores fly ash's larger ecological legacy in favor of concentrating just on the short-term advantages of lowering cement use.

Spending a lot of money and resources on a thorough investigation that looks into every possible aspect of applying fly ash in concrete may be necessary. Getting fly ash samples from several sources, assessing performance over an extended period of time, and making sure rules are followed all have the potential to raise expenses. Furthermore, if the study is time-constrained, it might not have the means to thoroughly investigate some topics, such the viability of utilizing fly ash in big construction projects.

1.6. Significance of the study

1.6.1. Personal benefits

Personally, this course has improved my skills in experimental design, data analysis, and problem-solving by giving me invaluable practical experience with cutting-edge methods combining materials science and engineering. It gives me the chance to learn more about sustainable construction methods, which are becoming more and more in-demand in the labor market. Working on a project this creative and ecologically concerned could also lead to networking possibilities with companies and people interested in green building technologies, which could open doors for future career advancement.

1.6.2. Academic benefits

From an academic standpoint, this work adds a great deal to the corpus of information about sustainable building materials. Researchers and students can close gaps in the literature and advance the field of civil and environmental engineering by investigating the technical characteristics and fly ash's potential use in concrete. The results may stimulate more research into the best way to optimize supplemental materials, spur new developments in material science, and shape curriculums that emphasize sustainable growth in the future.

1.6.3. Social-economic benefits

The study's findings may have a big impact on lowering construction costs from a socioeconomic standpoint, especially in underdeveloped nations where fly ash is widely accessible but rarely used. The construction sector might lessen its reliance on more expensive cement by encouraging the use of fly ash as a supplement to cement, which would cut overall building costs and increase accessibility for infrastructure projects. Additionally, by recycling industrial waste, promoting sustainability objectives, and fostering a more resource-efficient economy, the use of fly ash could help minimize environmental problems, hence it will help the Rwandan society.

1.7. Organization of The Thesis

The thesis is organized in five chapters. The first chapter which is the introduction of the study, the second is the literature review, the third is the methodology used to collect and analyze data, the fourth is the interpretation of results obtained after research and data analysis, and the fifth is the conclusion and recommendations of the study.

CHAPTER ONE: General introduction which deals with Introduction,background of the study, problem statement, research objectives, research questions, scope and limitation of the research, significance of the study, and finally organization of the study.

CHAPTER TWO: Literature review, to give all the details and theories concerning the construction of peat coal fly ash.

CHAPTER THREE: Materials and methods, which deals with the methods, procedures, the definitions of the instruments that were used for the investigations and, the methods and techniques, used to collect all the data required.

CHAPTER FOUR: Results and discussions, that handles the findings' presentation, analysis, and interpretation about peat coal fly ash as a cement complement in concrete.

CHAPTER FIVE: Conclusion and recommendations, which is the last, present conclusions, recommendation to state the output of the overall research**.**

CHAPTER TWO: LITERATURE REVIEW

2.0. Introduction

This chapter summarizes the information obtained from the previous research conducted on the use of peat coal fly ash as complement of cement in concrete. The integration of peat coal using fly ash as an additive while building with concrete has garnered significant attention within the construction industry. This literature review provides a concise overview of the technical aspects associated with incorporating peat coal fly ash into concrete projects. By examining existing research and studies, this review seeks to elucidate the impact of peat coal fly ash in concrete structures, its potential sustainability advantages, and the challenges entailed in its utilization. Through a comprehensive exploration of the existing body of literature, this study aims to offer insightful observations into the viability and efficacy of employing peat coal fly ash as a complementary material in concrete applications.

2.1. Building materials

All civil engineering constructions are built on the foundation of construction materials. Roman concrete, also known as opus cementitious, was a building material utilized in classical Rome. Hydraulic-setting cement served as the foundation for Roman concrete. Because pozzolanic ash is incorporated, which stops cracks from expanding, it is durable. The material was widely used by the middle of the first century, usually in brick-faced construction, and different aggregate combinations allowed for other material combinations (Katuwal, 2019).

2.1.1. Concrete

The most commonly utilized material is concrete and it is the mostly produced building material among all others based on cement due to its easy availability, low cost of production, and straightforward construction. The most well-known advantage of concrete is its highest compressive strength. During the initial stages of concrete material development, numerous reinforced concrete structures failed to meet their intended lifespan due to the rising use of these materials. As a result, many investigators attributed this to subpar construction quality or unconventional design (Prem et al., 2024).

It is preferable to choose new building materials after making sure the following minimal technical alternative requirements are met: What is a material's maximum strength? To what extent is it robust? In what way does it increase or decrease the overall structure's serviceable life? In the event that the technical criterion is met, the cost considerations should be finalized (Uyanik, 2019).

Approximately 60% of the overall cost of a building project is concerned with the cost of building materials. There are numerous reasons that contribute to the high cost of building materials. Poor handling and theft are two reasons why building materials on a project site can become more expensive overall. Baked clay bricks are used in the construction of over 75% of buildings in Rwanda. Given that the focus of this technical research study is concrete construction, it is vital to examine concrete as a building material and its function in construction (Elsharawy, 2024).

2.1.2. Composition of concrete

Cement, water, and fine and coarse aggregate are the ingredients of concrete. It must, nevertheless, adhere to the necessary and ideal standards for durability and strength. Rome in 600 BC: While not the first people to make concrete, it was deeply used by the Romans. The Romans were successfully utilizing concrete in most of their construction activities by 200 BC. To create the combination, they combined lime, seawater, and volcanic ash. After the mixture solidified, they piled the blocks like bricks inside wooden molds.

By 1300 BC, concrete was invented. The thin, damp glazing of charred limestone, when applied to the exterior of Middle Eastern fortresses and residential walls, reacts chemically with atmospheric gasses to form a hard, protective surface. Joseph Aspin did not create the Portland concrete that is used today. We are aware that the thermal materials we use today may not have achieved the high temperatures required. Currently, we have a standard cement recipe. Since 3000 BC, concrete has been improved—the Egyptian Pyramids. More than 5000 years ago, the Egyptians constructed the pyramids using the first concrete forms. 300 BC–476 AD Roman Architecture Animal products were first used to cement by the Romans of early time, who went on to build several architectural marvels including the Pantheon. 1836: Testing of Cement in Germany, the initial tests of compressive and tensile strength were carried out in 1836. This was the world's first reinforced concrete bridge, and in 2016, a 3D printed building in Dubai became the first completely operational structure ever constructed. Adrian Smith, Skidmore, and Owings & Merrill constructed the Burj Khalifa for the One World Trade Center (WTC) and the Willis Tower. Concrete will still be used to create creative structures, including houses, flats, hotels, sculptures, and a lot more. Stunning in its own right, concrete is now the most popular building material worldwide. The future of concrete looks bright as new innovations in technology increases its strength, sustainability, and possible applications (Haupt, 2024).

2.2. Conceptual review

Cement is a fine powder made from limestone, clay, and other minerals, which are heated to high temperatures to produce a material called clinker. When cement mixed with water, it undergoes a chemical reaction known as hydration, which binds the particles together and forms a solid matrix. This resulting hardened material is what we commonly refer to as concrete (Luan *et al.*, 2021).

Conversely, fly ash is a byproduct of coal combustion in power plants. It consists of tiny, spherical particles that can be collected from the flue gases. Fly ash is often categorized into two types: Class C and F. The fly ash class F is low-calcium, while fly ash class C is high-calcium. Both types of fly ash are used in construction, but they have different properties and applications.

2.2.1. Use of both cement and fly ash in construction

Fly ash and cement are so important during construction process. They are constituents of what makes a real concrete apart from sand, coarse aggregate and water (Tariq *et al.*, 2022). Their use in construction can be enumerated in various ways. The following are their main uses in construction industry:

- ✓ **Strength and Durability:** Cement provides the structural strength of concrete, while fly ash enhances its durability. The permeability of concrete is decreased by the addition of fly ash, making it less susceptible to water and chemical penetration, which can lead to degradation.
- ✓ **Sustainability:** Fly ash is considered a sustainable material because it repurposes a waste product (coal ash) and reduces the demand for traditional cement production, which is energy-intensive and emits carbon dioxide.
- ✓ **Workability:** The addition of fly ash can improve the workability and cohesiveness of concrete mixtures, making them easier to handle during construction.
- ✓ **Cost-Efficiency:** By using fly ash in place of some of the cement, construction projects can reduce costs while maintaining the required structural performance.

2.2.2. Use and contribution of cement versus fly ash to concrete structures

In concrete mixtures, fly ash and cement are typically combined with aggregates (such as sand and gravel) and water to create a workable blend. Here’s how they contribute:

- ✓ **Cement:** provides the initial binding properties in concrete, helping it set and harden. It plays a crucial role in achieving the desired compressive strength.
- ✓ **Fly Ash:** serves as an additional cementitious material. When fly ash is added to the mix, it reacts with the calcium hydroxide formed during cement hydration to create

additional chemical bonds. As a result, there is less free lime in the concrete and enhances long-term strength and durability.

2.2.3. Relationship between fly ash and cement in concrete production

To take advantage of their complementing qualities, cement and fly ash are frequently used in concrete compositions. We refer to this mixture as a pozzolanic blend. The specific ratio of cement to fly ash can vary depending on the desired properties of concrete and local construction standards (Aliansyah and Firdaus, 2024).

2.2.4. Standards application in construction

ASTM (American Society for Testing and Materials) and ACI (American Concrete Institute) and also local standards organizations often provide guidelines for applying fly ash in concrete. However, it’s important to check if there are specific standards or recommendations for the use of peat coal fly ash in your region. These standards will outline acceptable levels of key properties, like chemical composition, particle size distribution, and pozzolanic activity.

Pozzolanic Activity: Peat coal fly ash should exhibit pozzolanic activity, which is the ability to react with calcium hydroxide to form additional chemical bonds in the concrete matrix. Standards may specify minimum pozzolanic activity requirements to ensure the fly ash's effectiveness in improving concrete properties (Shanmugapriya and Chinnaraju, 2024).

Different important points said by authors around the world about the percentages used when mixing or adding fly ash in concrete. The impact of class F pond ash (PA) on the stabilization behavior of peat. Different proportions of FA (5%, 10%, 15% and 20%) were used with different curing periods and mainly Unconfined Compression Strength (UCS) test was conducted. It was observed that UCS increased with the increase in percentage of FA and curing period.

Fly ash (FA) was used as a pozzolana in this study to improve the stabilized peat columns' long-term strength accumulation at the experimental scale. The main goal of the research was to create an appropriate blend of silica sand, FA, calcium chloride ($CaCl_2$), and Portland composite cement (PCC) that could be used to create stabilized peat columns. To find out the relevant variables affecting the stabilized peat's UCS, a laboratory-based method was started. It was discovered that the best way to stabilize peat is to use a mix design that substitutes 10% of the PCC with FA.

In order to produce high-strength concrete, this study looks into the highest percentage of fly ash that can be used in place of some Original Portland Cement (OPC). Many researchers have found that the incorporation of industrial by-products like fly ash as in producing concrete can improve properties of concrete in both its fresh and hardened states. The water-binder ratio was used 0.30. The highest size of coarse aggregate in the used sand, which was medium sand, was 20 mm. Bosowa Type I cement was used in this instance. The cement that PT Bosowa produces. In this study, fly ash was added to binder in the following percentages: 0, 10, 15, 20, 25, and 30%. The super plasticizer utilized was Naptha 511P. The results showed that the replacement cement up to 25 % of the total weight of binder resulted compressive strength higher than the minimum strength at one day of high-strength concrete (Alaj et al., 2024).

The utilization of waste materials in concrete provided numerous benefits, demonstrating the material's strength, durability, and workability while also assisting with sustainable development initiatives. One waste product from burning coal was fly ash. The purpose of this study was to determine whether using fly ash in place of some cement would result in high-strength concrete. In this study, fly ash was obtained from PLTU Mpanau Palu in Central Sulawesi. The water-binder ratio utilized in this study was 0.3, which was chosen from previously completed trial mixes. The results of this research showed that the fly ash concretes' strength was higher than concrete with PCC only. Using fly ash in place of cement concrete could be up to 20% to produce high strength concrete.

2.3. Theoretical review

2.3.1. Portland cement

Portland cement is the most common type of cement used worldwide as a basic ingredient in concrete, mortar, and non-specialty grout. It is the product of pulverizing clinker and consists of hydraulic calcium silicates to which some calcium silicates to which some calcium sulphate has usually been provided as an underground addition. Materials that contain appropriate amounts of calcium compounds, silica, alumina and iron oxide are crushed, screened and placed in a rotating cement kiln. Ingredients used in this process are typically materials like limestone, sandstone, marl, shale, iron, clay and fly ash (Bui *et al.*, 2023).

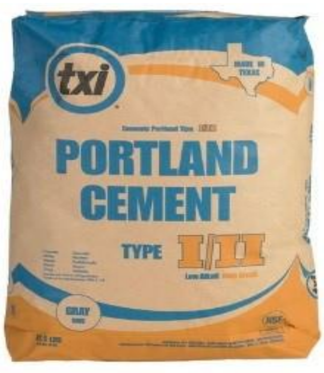

Figure 2. 1: Portland cement bag

2.3.1.1. Types of Portland cement

The most common types are type I, II, III, IV and V. Type I is also called Ordinary Portland Cement (OPC). Type I: This is the general-purpose cement. Normally this type of cement is utilized for general construction purposes such as bridge, building and precast construction.

Type II: Moderate sulfate resisting cement. This type of cement used where there is a potential for concrete to be attacked by sulfates. Such as substructure. Type I and Type II are almost the same based on their properties.

Type III: is high early strength cement and useful during cold weather concreting where quick strength gain is a factor. This Type produces more heat than type I.

Type IV: Low hydration heat. The name of this type of cement clears that it produces less heat during the hydration process thus useful for hot weather concrete. It is also useful for producing a large quantity of concrete.

Type V: High sulfate resistance cement. This type of cement is applied where there is a possibility to contact high sulfate with concrete. Compared to Type I cement, this type hydrates more slowly.

These types of Portland cement are produced by controlling the percentage of constituents of cement. There are also other three types of cement which are produced by mixing air entraining agent with a particular type of cement. Such as Type Ia, Type IIa and Type IIIa.

The makeup of types I, II, and III is the same as that of types Ia, IIa, and IIIa. The sole distinction is that an air entraining agent is mixed into the mixture in Ia, IIa, and IIIa. The air entrainment must meet the minimum and maximum optional specification found in the ASTM manual.

2.3.1.2. Classification of cement

The different classes of API cements for use at down hole temperatures and pressures are:

Class A

- This product is intended for use when special properties are not required.
- It is available only in ordinary, O, grade (like ASTM Spec. C150, Type I).

Class B

- This product is meant to be used in situations where a moderate to high level of sulfate resistance is required.
- It is available in both MSR and HSR grades (similar to ASTM Spec. C150, Type II).

Class C

- This product should be used in situations when great early strength is required.
- It is available in ordinary, O, MSR, and HSR grades (similar to ASTM Spec. C150, Type III).

Class G

- When making Class G well cement, no substances other than calcium sulfate, water, or both may be combined in or interground with the clinker.
- This product is meant to be used as a basic cement for wells. It is accessible in grades MSR and HSR.

Class H

- When making Class H well cement, no substances other than calcium sulfate, water, or both may be combined in or interground with the clinker.
- The purpose of this product is to serve as a basic well cement. Grades MSR and HSR are offered.

Table 2. 1: Classification of Portland cement

	Classification	**Characteristics**	**Applications**
TYPEI	General purpose	Fairly high C_3S content for good early strength development	General construction (most buildings, Bridges, pavements, precast units,
TYPEII	Moderate sulphate resistance	Law C_3A content (<8%)	Structures exposed to soil or water containing sulfate ions

TYPEIII	High early strength	Ground more finely, may have slightly more C_3S	Rapid construction, cold weather concreting
TYPEIV	Law heat of hydration (slow reacting)	Low content of C_3S (<50% and C_3A	Massive structures like dams. Now rare
TYPEV	High sulfate resistance	Very low C_3A content (<5%)	Structures exposed to high levels of sulfate ions
WHITE	White color	NO C_4AF, liw Mgo	Decorative (otherwise has properties same as for type I

Portland cement is made up of iron, calcium, silica, and alumina. While silica, alumina, and iron are obtained from sands, clays, and sources of iron ore, calcium is obtained from limestone, marl, or chalk.

2.3.1.4. Cement chemical composition

The normal composition of the cement clinker that is created looks like in the following table (Ghoddousi *et al.*, 2016).

Table 2. 2: Cement chemical composition

Compound	Formula	Shorthand form	% by weight
Tricalcium aluminate	$Ca_3Al_2O_6$	C_3A	10
Tetracalcium aluminoferrite	$Ca_4Al_2Fe_2O_{10}$	C_4AF	8
Belite or dicalcium silicate	Ca_2SiO_5	C_2S	20
Alite or tricalcium silicate	Ca_3SiO_4	C_3S	55
Sodium oxide	Na_2O	N	(Up to 2)
Potassium oxide	K_2O	K	(Up to 2)
Gypsum	$CaSO_4.2H_2O$	CSH_2	5
Others	-	-	2

2.3.1.5. Cement hydration

Cement hydration is the chemical reaction of cement with water to produce a binding medium. In this reaction is various cement composites react with water and it is exothermic. Portland cement is hydraulic cement; hence it derives its strength from chemical reactions between the cement and water. The process is known as hydration.

Hydration in concrete, Concrete derives its strength by cement particles hydration. The cement hydration is not a momentary action but a process continuing for long time. In order to maintain hydration, additional water needs to be provided to replace the water lost through evaporation and absorption. Therefore, the process of curing can be viewed as the establishment of an ideal environment for continuous hydration in the initial phase. The desirable conditions are, a suitable temperature and sample moisture.

2.3.2. Peat coal fly ash

Coal is a flammable black or brownish-black sedimentary rock, which is usually formed in lithostrata or veins known as coal beds or coal seams (Topark et al., 2015). Anthracite and other hard coal types that are categorized as metamorphic rocks are formed when sedimentary rocks are subjected to increasing temperatures and pressures. It is thought that old plant remains buried beneath the earth change into coal through: peat → lignite → bituminous coal → anthracite, and anthracite can be further converted into graphite.

Figure 2. 2: Coal

Fly ash is produced by coal-fired electric and steam generating plants. Typically, After being ground into a powder and thrown into the boiler's combustion chamber with air, the coal instantly ignites, creating heat and a molten mineral residue. Heat is extracted from the boiler via boiler tubes, which cools the flue gas and causes the molten mineral residue to solidify into ash. The lighter small ash particles, called fly ash, stay suspended in the exhaust gas while the coarser ash particles, called bottom ash or slag, descend to the bottom of the combustion chamber. Particulate emission control equipment, like electrostatic precipitators or filter fabric baghouses, remove fly ash before the flue gas is exhausted.

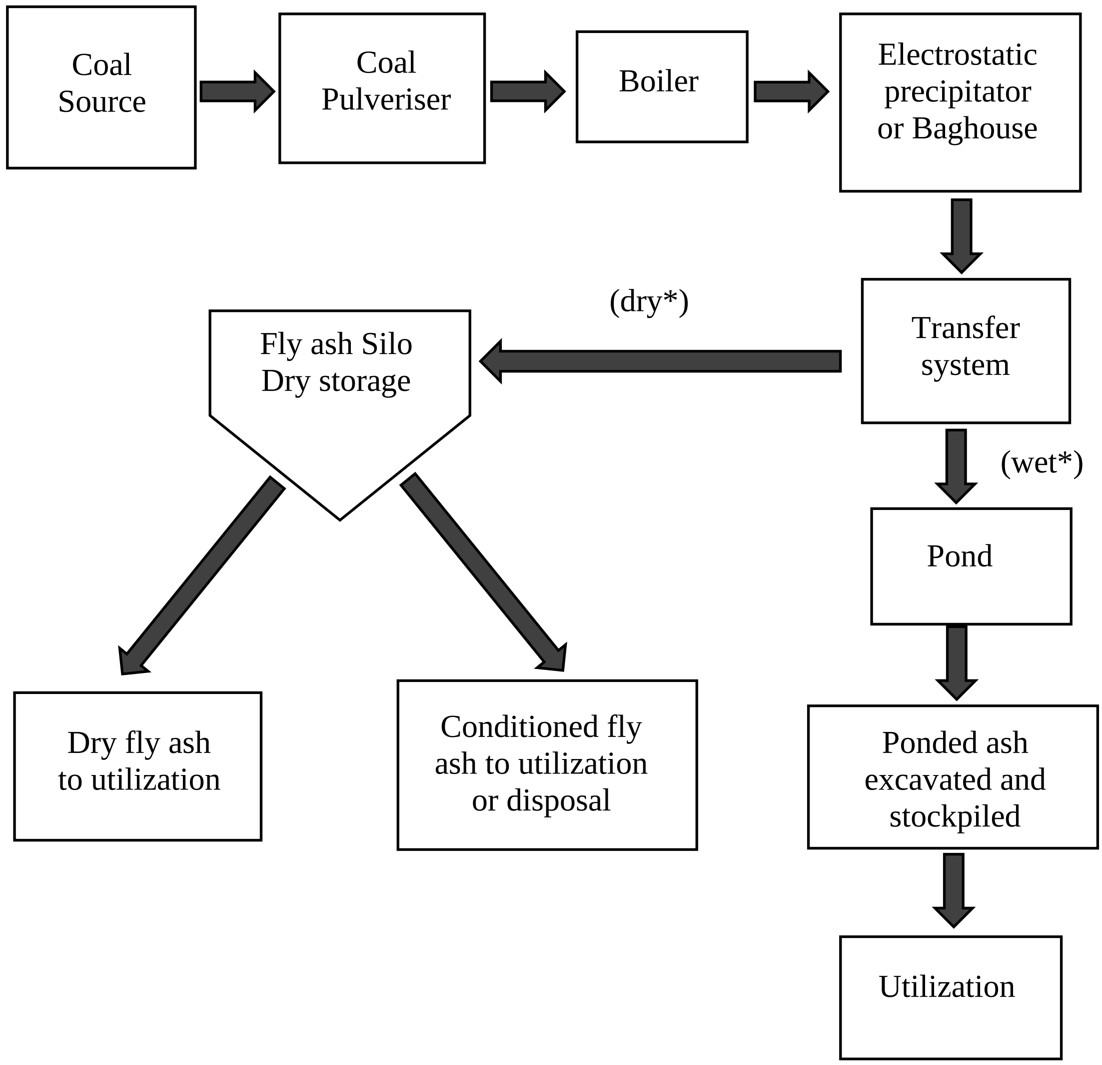

Figure 2. 3: Conditioned fly ash to utilization or disposal

2.3.2.1. Types of coal

Coal is classified into five categories: peat, lignite (brown, black), subbituminous, bituminous (raw), and anthracite, depending on the degree of carbonization. Anthracite has the highest degree of carbonization, whereas peat has the lowest (Maryoto *et al.*, 2020).

Figure 2. 4: Types of coal

With less than 60% of its carbon content, peat is the coal that has coalified to the least degree. The remnants of marsh plants, which are incapable of fully decomposing and building up in the presence of excessive moisture and nitrogen, are what give rise to peat (Wang *et al.*, 2021).

Table 2. 3: Identification of different types of coal

Type	**Peat**	**Lignite**	**Subbituminous**	**Bituminous**	**Anthracite**
Color	tan, black	brown to dark brown	dark brown to black	black	grayish black
Luster	None	Dark	bright jet-black	glossy	weak metallic
External Strip	native plant residue	not obvious	Obvious	strip shape	no obvious strip
Combustion	smoke, low calorific, no caking	smoke, low calorific value, no caking	smoke, less caking	smoky, high calorific, caking	smokeless, high calorific value, no caking
Moisture	70%-90%	25%～70%	15%-30%	5%-20%	5%-15%
Density	$0.8g/cm^3$	1.1-$1.4g/cm^3$	$\approx 1.4g/cm^3$	1.2-$1.4g/cm^3$	>1.35-$1g/cm^3$

Hardness	soft, spongy	Fragile	High	higher	High
Hydrocarbons	Yes	None	None	none	None
Humic Acid	Yes	Yes	No	none	None

Fly ash has been used in concrete for a long time. According to „M.S. Shetty" (Author of Concrete Technology Theory and Practice), that the first large scale use of fly ash was in the construction of Hungry Horse dam and later, Canyon Ferry dam in United States of America. Fly ash made up around 30% of the cement's weight. Fly ash was first employed in India during the construction of the Rihand Dam, where it was used in an amount equal to 15% of the cement used (Amat *et al.*, 2024).

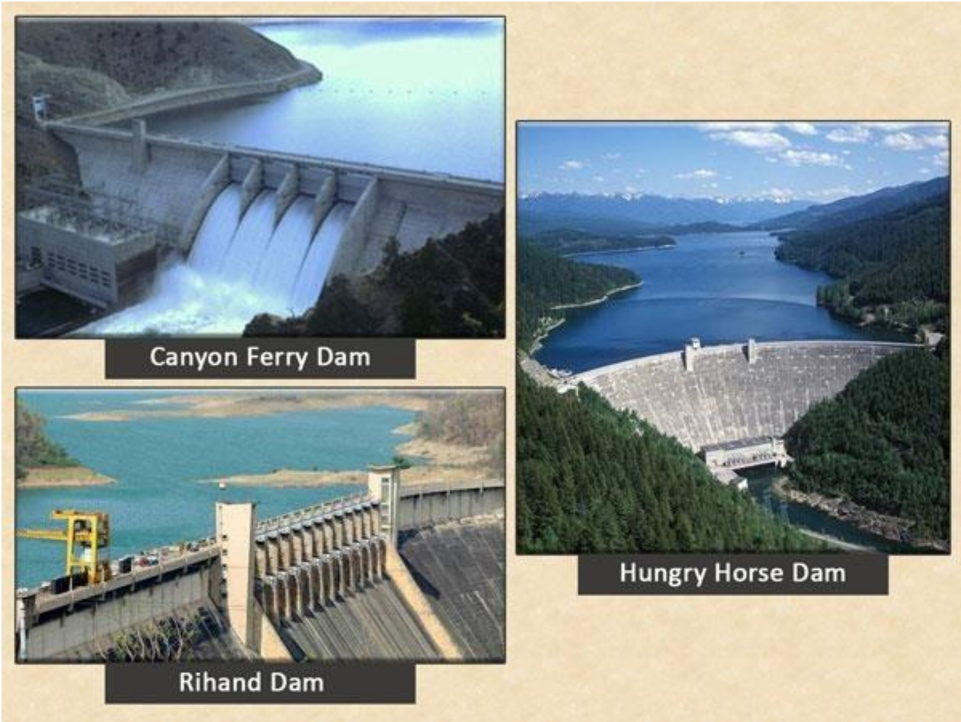

Figure 2. 5: Use of fly ash in different dams

The fly ash is the residue that is left from burning coal, and this is formed when the gaseous releases of the coal are efficiently cooled. It is somewhat like a glass powder that is fine in nature. However, the chemical constituents of this residue might vary from one to one.

Fly ash has several industrial applications and is widely found in power plant chimneys. The material is also used as substitute cement by mixing it with lime and water. The material is embedded with many beneficial features and so is being utilized as a significant building material for construction purposes. This form of concrete is substantially smoother.

Figure 2. 6: Fly ash and cement

2.3.2.2. Advantages of fly ash

The following are some benefits of incorporating fly ash in concrete: (Gulsan *et al.*, 2019):

- ✓ It is a cost-effective substitute for Portland cement.
- ✓ Since fly ash is a waste product or by-product, using it in concrete lowers CO2 emissions and is therefore environmentally beneficial.
- ✓ It can withstand cold conditions well.
- ✓ It's not a material that shrinks.
- ✓ Moreover, dense concrete or brick with a smooth surface and fine details can be produced using ground fuel ash.
- ✓ In comparison to regular concrete, fly ash concrete is far more workable and permits a smaller water-to-cement ratio for slumps that are comparable. Unlike other pozzolanic ingredients, which typically raise the water content of the concrete mix, fly ash.
- ✓ It lessens issues with bleeding, permeability, cracks, etc.
- ✓ Finally, it lowers the heat of hydration.

2.3.2.3. Application of ash

The fly ash can be used as prime material in many cement-based products, such as poured concrete, concrete block, and brick. Portland cement concrete pavement, also known as PCC pavement, is one of the most popular applications for fly ash (Dash et al., 2018).

PCC-based road construction projects can consume a lot of concrete, and employing fly ash in place of it has major financial advantages. Fly ash has also been utilized as mine fill and embankment, and the Federal Highway Administration is coming around to the idea more and more.

Typically, a ratio of 1/2 pound of fly ash for every 1 pound of cement is specified for substituting fly ash for Portland cement. To account for the increased volume of fly ash, the amount of fine aggregate in the concrete mix must be decreased.

In the above pages, we were talking about the amount of aggregate used in concrete and they have seen that the amount of aggregate used is 75% in concrete, 10% of cement and 15% of water.

2.3.2.4. Properties of fly ash

The fly ash is made up of tiny, powdery particles that are primarily spherical, hollow or solid in form, and glassy (amorphous). Fly ash contains carbonaceous material that is made up of angular particles. Most bituminous coal fly ashes have a particle size distribution that is similar to silt (smaller than a 0.075 mm or No. 200 filter). Compared to bituminous coal fly ashes, subbituminous coal fly ashes are often slightly coarser, although being silt-sized as well (Brooks et al., 2000).

Fly ash typically has a specific gravity of 2.1 to 3.0 and a specific surface area of 170 to 1000 m^2/kg (measured using the Blaine air permeability method). Fly ash's hue can range from tan to gray to black, contingent upon the quantity of unburned carbon present in the ash. The carbon content decreases with lighter color. Lignite, also known as subbituminous fly ashes, typically has a light tan to buff color, which denotes the presence of some lime or calcium and relatively low carbon levels. Bituminous fly ashes are often a gray color, with lighter gray tones typically denoting higher-quality ash.

Quality requirements for fly ash vary depending on the intended use. The properties of the fuel (coal), the co-firing of fuels (bituminous and sub-bituminous coals), and several facets of the combustion and flue gas cleaning/collection processes all have an impact on the quality of fly ash. For fly ash to be used in concrete, its four most important properties are loss on ignition (LOI), fineness, chemical composition, and homogeneity.

Fly ash's level of unburned carbon (coal) in the ash is measured, or LOI, and it's an important quality, particularly for concrete applications. Elevated carbon concentrations, the nature of carbon (activated), the way soluble ions in fly ash interact, and the variation in carbon content can all lead to serious air-entrainment issues in newly mixed concrete and negatively impact its durability. ASTM and AASHTO define LOI limitations. Some state transportation agencies, however, will have a lower LOI threshold. Fly ash can also be used to extract carbon. The LOI has no bearing on several uses of fly ash. Elevated carbon fly ash can be used as a filler in asphalt, flowable fill, and structural fills.

The ability of the coal to be ground into a fine texture and the state of the coal crushers are the two factors that most directly affect fly ash fineness. Fineness is the percentage by weight of the material retained on the 0.044 mm (No. 325) screen for fly ash used in concrete applications. A coarser gradation may have higher carbon concentrations and produce less reactive ash. ASTM and state transportation department specifications discuss maximum fine amounts. To increase the fineness and reactivity of fly ash, screening or air classification might be used in its processing.

Fly ash fineness does not influence some non-concrete applications, such as structural fillers. However, other applications such as asphalt filler are largely dependent on the fly ash fineness and its particle size distribution.

The source coal's mineral chemistry and any additional fuels or additives employed during the combustion or post-combustion stages have a direct impact on the chemical makeup of fly ash. The chemical makeup of the fly ash can also be impacted by the pollution control technique that is employed. Plants that produce electricity use a lot of coal from various sources. Blending coal can increase generating efficiency and enhance the environmental performance of the station. Fly ash's chemistry is continually assessed and tested for certain purposes.

Certain stations burn some coals more than others or change the composition of their additives to prevent ash quality from declining or to give fly ash the proper chemistry and properties.

To provide a constant product supply, fly ash properties must remain consistent from shipment to shipment. Since fly ash chemistry and properties are usually understood ahead of time, performance tests and design are conducted on concrete mixtures.

2.3.2.5. Physical properties of fly ash

Fly ash's physical characteristics are:

- ✓ **Fineness of Fly Ash:** both dry and wet sieving methods must be examined. A 45-micron sieve is used to sift the fly ash sample, and the percentage retained on the sieve is computed. The Lech atelier method and the Blaine Specific Surface approach are further techniques for measuring fineness (Choi et al., 2012).
- ✓ **Specific Gravity of Fly Ash:** It varies in value from a low of 1.90 for sub-bituminous ash to a high of 2.96 for bituminous ash that is rich in iron.
- ✓ **Size and Shape of Fly Ash:** Fly ash has a particle size range of 10 to 100 microns since it is an extremely tiny substance. Fly ash typically has a spherical, glassy form.
- ✓ **Color:** The chemical and mineral components of fly ash determine its color. Tan and light colors are produced by the fly ash's lime content, whereas brownish colors are

produced by the iron content. Generally speaking, a dark gray to black tint indicates an increased amount of unburned material.

2.3.2.6. Chemical properties of fly ash

The qualities of the burned coal and the methods of handling and storing it have a significant impact on the chemical makeup of fly ash. There are basically four types, or ranks, of coal, each of which varies in terms of its heating value, its chemical composition, ash content, and geological origin. The four types, or ranks, of coal are anthracite, bituminous, sub bituminous, and lignite. Fly ash can be handled dry, conditioned, or wet, but it can also occasionally be categorized based on the kind of coal that was used to make it (Das and Pandey, 2011).

According to the loss on ignition (LOI), the main ingredients of bituminous coal fly ash are silica, alumina, iron oxide, and calcium, with varied levels of carbon. In comparison to bituminous coal fly ash, lignite and subbituminous coal fly ashes have higher calcium and magnesium oxide concentrations, lower percentages of silica and iron oxide, and a lower carbon content. There is very little anthracite coal fly ash produced since utility boilers consume very little anthracite coal.

Table 2. 4: Chemical composition of fly ash

Component	Bituminous coal	Sub bituminous coal	Lignite coal
SiO_2 (%)	20-60	40-60	15-45
Al_2O_3 (%)	5-35	20-30	20-25
Fe_2O_3 (%)	10-40	4-10	4-15
CaO (%)	1-12	5-30	15-40
LOI (%)	0-15	0-3	0-5

Compares the normal range of the chemical constituents of bituminous coal fly ash with those of lignite coal fly ash and sub bituminous coal fly ash. The table clearly shows that compared to fly ashes from bituminous coals, lignite and subbituminous coal fly ashes have a larger calcium oxide content and a smaller loss on igniting. Fly ashes from lignite and sub-bituminous coal may contain more sulfate compounds than fly ashes from bituminous coal.

The amount of calcium as well as the ash's silica, alumina, and iron contents are the main distinctions between Class F and Class C fly ash. Total calcium in Class F fly ash usually varies from 1 to 12 percent. This is mostly composed of glassy components, calcium hydroxide, and calcium sulfate in combination with silica and alumina. On the other hand, calcium oxide contents in Class C fly ash could have been as high as 30 to 40 percent. Another distinction between Class F and Class C is that the amount of alkalis (combined sodium and potassium) and sulfates (SO_4) are often larger in the Class C fly ashes than in the Class F fly ashes (Mahajan et al., 2020).

Table 2. 5: The typical range of composition for fly ash made from several types of coal

Component	**Bituminous Lignite**	**Sub bituminous**
SiO_2 15-45	20-60	40-60
Al_2O_3 Oct-25	May-35	20-30
Fe_2O_3 Apr-15	Oct-40	04-Oct
CaO 15-40	01-Dec	May-30
MgO 03- oct	0-5	01-Jun 03-
Na_2O 0-6	0-4	0-2
K_2O 0-4	0-3	0-4

2.3.2.7. Addition process of fly ash in concrete

The fly ash has two possible use. When preparing concrete on the job site, add fly ash as an additive. Portland pozzolana cement (PPC) is made by blending a specific ratio of fly ash with cement clinker in the factory (Mousavi Nezhad and Newtson, 2024).

Both methods of adding fly ash are advantageous, but the second approach allows the engineer or user to vary the percentage addition of fly ash with more freedom and flexibility. 15–35% of fly ash by weight of cement is recommended for regular concrete construction; however, up to 70% of fly ash by weight of cement can be added for large-scale concrete projects like dams and retaining walls.

2.3.2.8. Classification of fly ash

Fly ash is classified differently according on the codes that are utilized. They are:

1. Type of Fly Ash as per IS Codes (IS 3812-1981)

A. Grade I: The bituminous coal used to produce this grade of fly ash has fractions $SiO_2+Al_2O_3+Fe_2O_3$ greater than 70 %.

B. Grade II: This grade of fly ash is made from fractionated lignite coal $SiO_2+Al_2O_3+Fe_2O_3$ greater than 50 %.

2. Type of Fly Ash as per American Society for Testing and Materials (ASTM C618) As a consequence of the chemical analysis that follows, fly ash is divided into two categories by ASTM based on the type of coal (Shen, 2024). Those are:

A. Type C: Additionally, resistant to chemical attack-induced expansion is fly ash. It is more frequently used for structural concrete and contains a higher amount of calcium oxide than Class F. Fly ashes with a high calcium content and less than 2 percent carbon content are usually classified as class C fly ash. Fly ash is being used in more than half of the concrete built in the United States. The kind and degree of reactivity of the fly ash determine the dosage rates. Generally, 15 to 25 percent by mass of cementitious material is the dose for Class F fly ash and 15 to 40% by mass of Class C fly ash.

B. Type F: flParticles of melted glass can be found in fly ash. This significantly lowers the possibility of growth brought on by sulfate attack, which can happen in fertilized soils or close to the coast. Class F typically has less than 5% carbon, but occasionally as much as 10% carbon. It is also low in calcium.

Figure 2. 7: Classes of fly ash

3. Type of Fly Ash based on boiler operations

Low temperature (LT) fly ash: When the temperature of combustion is lower than 900°C, it is created.

High temperature (HT) fly ash: It is produced out of combustion temperature below 1000°C.

2.3.2.9. Mechanism of fly ash

About half of Portland cement is made up of the principal material tri-calcium silicate, which when hydrated produces calcium silicate hydrate and calcium hydroxide. This is the chemistry of Portland cement hydration (Lou et al., 2024).

Since the main component of fly ash is non-crystalline silica glass, if we have Portland cement and fly ash is the pozzolana, it can be represented by silica. When Portland cement hydrates, the silica and calcium hydroxide are liberated.

Since calcium hydroxide in hydrated Portland cement adds little strength, reactive silica is used in its place. It creates more calcium silicate hydrate, a binder, slowly and steadily filling the area and providing us with strength and imperviousness (Muthusamy *et al.*, 2024).

Table 2. 6: hydration reaction of Portland cement and fly ash Portland cement

Hydration Process	**Tricalcium Silicate**	+	**Water**	=	**Calcium silicate hydrate**	+	**Calcium hydroxide**
Portland cement	C3S	+	H	=	C-S-H	+	CH
Portland cement + fly ash	S (silica + fly ash)	+	CH	=	C-S-H		

2.3.2.10. Benefits and uses of fly ash

Below is a list of fly ash's principal applications (Carmal, 2024):

- ✓ In the production of Portland cement.
- ✓ Usually employed in the construction of embankments.
- ✓ Used as a stabilizing agent for soil.
- ✓ Additionally, fly ash is a component in the creation of flowable fill.
- ✓ Used as a mineral filler to fill up gaps when laying asphalt roads.
- ✓ Fly ash is a component utilized in geopolymers.
- ✓ Used in concrete dams that have been roller-compacted.
- ✓ Used in the production of bricks made from fly ash.

- ✓ Fly ash functions as a catalyst when it is treated with silicon hydroxide.

The fly ash benefits consist of the following:

- ✓ Generates several scheduled times
- ✓ Resistance to cold weather
- ✓ High strength increases based on application
- ✓ Potential for use as an additive
- ✓ Thought to be a non-shrinking material
- ✓ It yields dense concrete with a smooth surface and crisp details
- ✓ It has excellent workability
- ✓ As opposed to no-fly-ash mixes, it lowers CO_2 emissions, permeability, bleeding, and crack issues. It also lowers heat of hydration and permits a lower water-cement ratio for slumps of a similar size.
- ✓ In certain markets, fly ash can be an affordable alternative to Portland cement.
- ✓ Because it is a byproduct and has a low embodied energy, a measurement of the energy required to produce and ship a building material. The fly ash is also acknowledged as an environmentally friendly material. It also uses less water than Portland cement and is simpler to use in cold climates.

2.4. Empirical review

Quality tests on concrete are performed as a part of quality control of concrete structures. To ensure the quality of the concrete supplied for a certain specification, several quality tests are conducted on the material, including compressive strength testing, slump tests, permeability tests, etc. (cementconcrete.org, Slump Test of Concrete, slump cone for Workability – Procedure, Apparatus, 2019-2020).

2.4.1. Tests done on fresh concrete

1. Slump test
2. Compacting factor test
3. Vibe test
4. Flow table test

2.4.2. Tests done on hard concrete

Concrete can undergo a variety of tests after it has solidified to demonstrate that it can function as intended or, in the event that its past is unknown, to identify its properties. When testing fresh concrete, this often entails casting sample and assessing them for different qualities as the concrete ages (Presa et al., 2024). The most popular test, known as the "concrete cube test," is the accepted way to determine compressive strength in quality control applications. Cast cylinders can be used to evaluate tensile strength, and concrete beam specimens are utilized to test flexural strength. Samples for numerous more tests, such as those measuring drying shrinkage, heat coefficient, and modulus of elasticity, can be prepared simultaneously (Saha et al., 2022).

Figure 2. 8: Example of hardened concrete

Tests performed on hardened concrete are:

- ✓ Compressive strength test (most common)
- ✓ Modulus of Elasticity
- ✓ Split-tension test
- ✓ Flexural strength test
- ✓ Rebound hammer test
- ✓ Penetration resistance test
- ✓ Ultrasonic pulse velocity test
- ✓ Maturity test

Compressive strength test

The water-to-cement ratio, cement strength, concrete material quality, quality control during the concrete production process, etc. are some of the variables that affect the compressive strength of concrete.

Test for compressive strength is carried out either on a cube or cylinder. Various standard codes recommend a concrete cylinder or concrete cube as the standard specimen for the test. ASTM C39/C39M, the Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, is provided by the American Society for Testing Materials.

The ability of a material or structure to bear loads that tend to diminish size as opposed to loads that prefer to elongate is known as compressive strength. Put differently, tensile strength opposes tension (being pulled apart), whereas compressive strength resists being pressed together. Tensile strength, compressive strength, and shear strength can all be examined separately in the research of material strength (Xu *et al.*, 2023).

Depending on the aggregate size, two different types of specimens—cubes measuring 15 cm by 15 cm by 15 cm or 10 cm by 10 cm by 10 cm, are employed for the cube test. 15 cm by 15 cm by 15 cm cubical molds are frequently used for the majority of the creations.

In order to prevent voids, this concrete is carefully mixed and put into the mold. These molds are taken out after a day, and test specimens are then submerged in water to cure. The specimens' upper surfaces ought to be uniformly smooth. This is accomplished by applying cement paste evenly over the entire specimen area.

After 7 or 28 days of curing, these specimens are sent through a compression testing equipment. Until the specimen fails, a load of 140 kg/cm^2 per minute should be given progressively.

The concrete's compressive strength is calculated by dividing the load at failure by the specimen's area.

Figure 2. 9: Concrete cubes specimens and compressive machine

The table below lists the grades of concrete along with the appropriate mix ratios.

Table 2. 7: Concrete mix ratio based on concrete grade

Grade	Mix ratio
M5	1:5:10
M7.5	1:4:8
M10	1:3:6
M15	1:2:4
M20	1:1.5:3

Ordinary concrete with grade up to M20 can be designed by nominal mix concrete procedure. Standardized recommended mix design procedures should be used to create high-strength and standard concrete (Kim *et al.*, 2012).

In most cases, the ratio of fine aggregate to coarse is to 1:2, but based on the size difference it shall be between 1: 1.5 and 1: 2.5.

Table 2. 8: Compressive strength of grades of concrete at 7 and 28 days

Grade of concrete	Minimum compressive strength (N/mm^2)	Specified characteristics compressive strength (N/mm^2) at 28 days
M15	10	15
M20	13.5	20
M25	17	25
M30	20	30
M35	23.5	35
M40	27	40
M45	30	45

2.5. Gaps in current research

Although there are still certain gaps in the current study, fly ash substitutes for cement in concrete has made considerable progress. One of the key issues is that fly ash's chemical composition varies greatly depending on the source, particularly coal-fired power plants. The variable pozzolanic characteristics, reactivity, and durability increases of different fly ash types make it challenging to ensure consistent quality and performance of fly ash in concrete. Particularly for high-performance or high-strength concrete applications, research has not yet fully addressed how these variances affect sustainability and long-term performance in a variety of environmental situations (Castro and Roesler, 2022).

There are still many questions about the widespread use of fly ash in the production of concrete, particularly in regards to supply and environmental impact. A byproduct of burning coal, fly ash may not be available in large quantities due to the global reduction in coal-fired power plants. Additionally, not enough research has been done to determine the potential environmental effects of using fly ash from industrial processes, especially the long-term leaching of potentially harmful substances. Although there has been much discussion about the environmental benefits of using less cement, a more complete life cycle analysis of fly ash-infused concrete is still missing.

2.6. Future research directives

Future research should focus mostly on the heterogeneity in the chemical and physical properties of fly ash from different sources. This can entail creating predictive models and standardizing testing procedures to see how these variances impact concrete performance over time. When maximizing fly ash for use in concrete, researchers should concentrate on maximizing fly ash from unconventional sources such waste incinerator facilities or biomass combustion, while also taking environmental safety and reactivity into consideration. An essential subsequent action is to comprehend how different fly ash types affect the mechanical characteristics and resilience of concrete under diverse stressors, such as high temperatures and chemical exposure.

Moreover, a primary consideration must be the fly ash utilization's long-term sustainability. The supply of suitable fly ash should be increased through research, whether by enhancing existing technologies to handle ashes of lower quality or exploring other materials. It is recommended that forthcoming research include a circular economy framework in order to assess the wider ecological and financial consequences of utilizing fly ash in the manufacturing of concrete. This means studying how fly ash reduces the carbon footprint of concrete and developing strategies to minimize any possible drawbacks while maximizing its contribution to the overall decrease in the usage of cement.

CHAPTER: MATERIALS AND METHODS

3.0. Chapter review

This chapter describes the methodology used to carry out the technical study on the use of fly ash as a cement supplement in concrete. This chapter goes into great detail on the study materials, the study area, the research strategy, and data collection and analysis methods. Additionally, it displays the hardware and software used to process the information and analyze the outcomes. The particular goals of this study are what this investigation aims to achieve. The strategies listed below are intended to methodically accomplish these goals.

3.1. Description of Study Site

The country of Rwanda in the *Figure 3. 1* below, is approximately located at 2^{o}South from the equator and 30^{o}East of Greenwich meridian. The population of Rwanda is approximated to 14,312,501 people in 2024 as projected by the United Nations (UN). The surface area cover of Rwanda is around 26,338 km^2, thus comparing to the number of citizens, making rising the need for storey houses. These houses need concrete structures, hence this study comes into play, to provide a sustainable technology and more economical way of producing concrete in Rwanda.

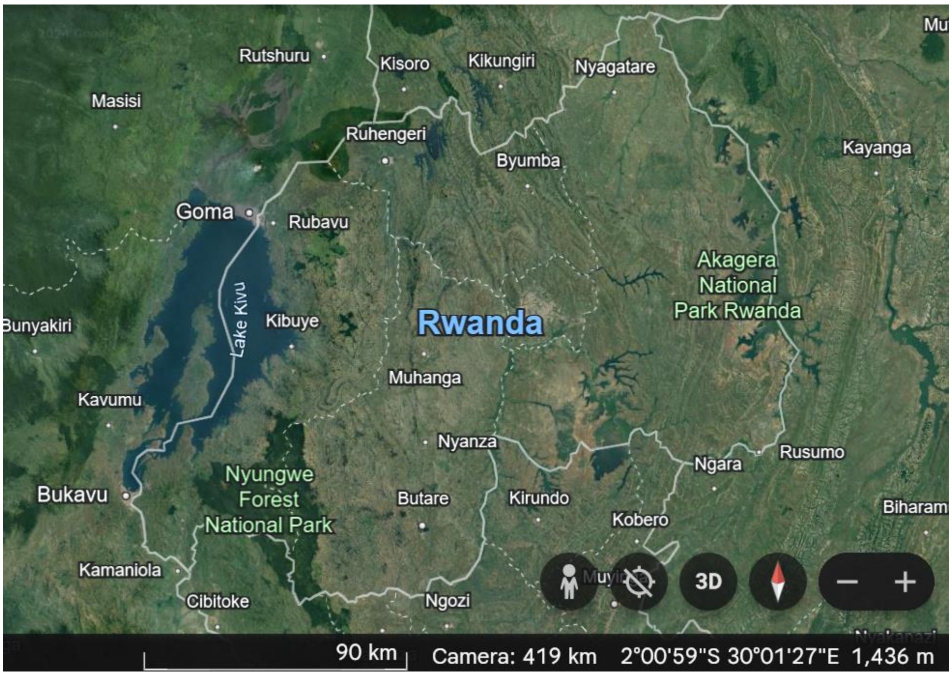

Figure 3. 1: Rwanda location by Google Earth

3.2. Research design

A quantitative experimental design is used in this investigation. A range of laboratory experiments are performed on concrete samples that have been made with varying ratios of fly ash to cement content in order to examine its mechanical, chemical, and physical characteristics. The research design of this study is structured and explained into three phases that can be described by the *Figure 3. 2* below starting at phase 1 and ending at phase 3.

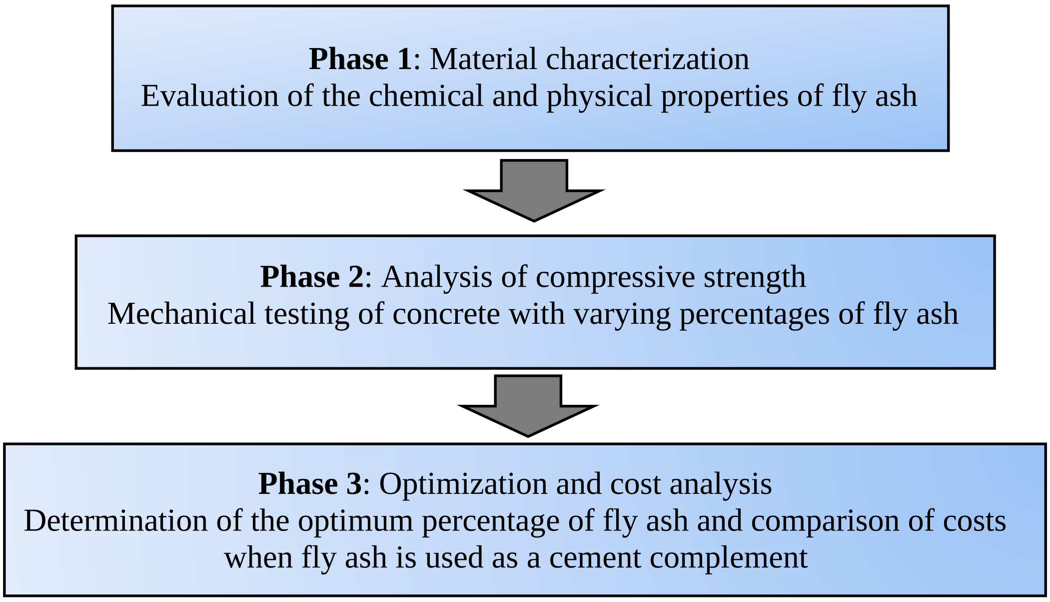

Figure 3. 2: Research design phases

3.3. Materials

These are materials used to carry out tests or experiments that reflected their use on the project, each of the ingredients for the concrete was measured by weight using a balance or by size using sieve. These materials are peat coal fly ash, cement, fine aggregates, coarse aggregates and water.

3.3.1. Fly ash

Utilized fly ash comes from a nearby coal-fired power station. Fly ash employed in this study is categorized according to ASTM C618 standards; it is most likely Class F fly ash, which is recognized for its pozzolanic qualities. Fly ash used in this experiment was obtained from burning peat coal which is located at Gisagara District, Southern Province because there was place where we found peat coal power station and were easily for us to get the fly ash its transportation from the factory, a sample is shown on the figure below.

Figure 3. 3: Fly ash

3.3.2. Cement

The control cementing material is Ordinary Portland Cement (OPC). The cement used in the experimental work was TWIGA/CEMERWA ordinary Portland cement with a characteristic compressive strength of 42.5 N/mm^2 and conformed to the requirements of BS EN 196-2: 2005 as demonstrated in the following figure.

Figure 3. 4: Twiga Cement

3.3.3. Fine Aggregates

In the concrete mix design, river sand from Kayumbu quarry in Southern Province was used as fine aggregate (sand). After the contaminants were eliminated, the fine aggregates met the specifications needed for experimental work and complied with BS 812-103 standards.

Figure 3. 5: Kayumbu sand

3.3.4. Coarse Aggregate

These are the unprocessed components that are necessary for making concrete. The aggregates used in the concrete mix needed to be pure, hard, strong, and devoid of contaminants. As seen in the picture, coarse aggregates that are readily available locally have been employed.

Figure 3. 6: Coarse aggregate

3.3.5. Water

Since water actively participated in the chemical reaction with cement and fly ash from peat coal, it is a crucial component of concrete. Since water contributed to the formation of the cement gel that gave it strength, it was necessary to pay close attention to both its quantity and quality. There were no unfavorable organic or inorganic elements present in high amounts in the mixing water.

3.4. Tools and equipment used

Tools were items or things used to mix the concrete. Each tool had its role as explained below:

3.4.1. Balance

As seen in the picture below, it was utilized to compute the weights of the mix proportion of the samples as well as to obtain dry and wet masses of sand and PFA sand-cement blocks.

Figure 3. 7: China electronic laboratory digital scale 600g – 0.5g

3.4.2. Steel mould

In this study, steel moulds were used while operating the tests. This was used for cubes manufacturing as they were made by using a simple cube-making operated manually. The mould was initially oiled before placing the concrete in it in order to prevent the concrete to stick on the side of the mould as shown on the following figure.

Figure 3. 8: Steel mould

3.4.3. Tamping rod

To remove air spaces from the concrete mixture, a tamping rod was utilized. As seen in the figure below, the concrete was layered into the mold and crushed using a tamping rod after each layer was added.

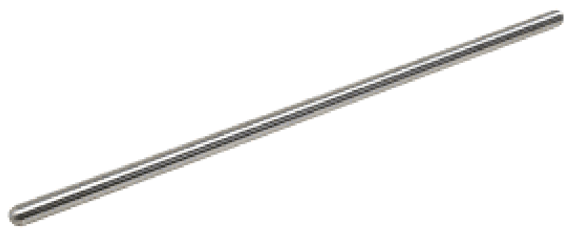

Figure 3. 9: Tamping rod

3.5. Methodology for collecting data

The analysis method was a proven practice for making the tests following various steps including batching and mixing of materials, concrete mix design, casting of specimens, and curing of specimens. Strategies followed in this study were to achieve the targets or aims of the study successfully and were described in this chapter.

Slump test and compressive strength tests were conducted in this study, and references were made to two variables: curing time and PFA percentages. The diagrams below illustrate these references, with curing times for each PFA percentage representing 7, 14, and 21 days.

3.5.1. Preparation of testing specimens

Concrete specimens underwent tests to assess and examine the objectives of the compressive strength and cube density tests; these tests necessitate the following processes;

3.5.1.1. Batching and mixing of materials

Materials were grouped according to weight. The percentages at which Peat Fly Ash (PFA) replaced Ordinary Portland Cement (OPC) were 5%, 10%, 15%, and 20%. The 0% sample was done to serve as control for other samples, in order to compare with the other percentages.

To prevent losing water or other components, the concrete was manually mixed. Dry mixing of the cement and fine aggregates was done until the material was well combined and had a consistent color (Ahmadi, 2000). After that, water was added and the entire batch was mixed until the concrete looked homogenous and had the appropriate consistency. The coarse aggregate was then added and mixed with the cement and fine aggregate until the coarse aggregate was evenly dispersed throughout the batch.

3.5.1.2. Concrete Mix Design

The concrete mix design, as displayed in the table, has the mix designation (M), which is followed by a sequential numbering system and a description (Liu *et al.*, 2021).

Binder, sand, and gravel were utilized to make the concrete employed in this investigation. Targeting the M20 grade, the concrete mix percentage was 1:1.5:3, and it was utilized in accordance with weight as described in the preceding chapter and in the table displaying the data used to make the concrete.

Table 3. 1: Mix Portion for different percentages of PFA

Mix destination	**Description**
Trial 1	Control concrete
Trial 2	5% PFA+95% Cement
Trial 3	10% PFA+90% Cement
Trial 4	15% PFA+85% Cement
Trial 5	20% PFA+ 80% Cement

3.5.1.3. Casting of specimens

Concrete examples of 150 x 150 x 150 mm were produced using cubic iron molds to determine all measurements. In order to prevent the concrete from clinging to the sides and bottom of the steel mold, the molds were thoroughly cleaned by putting mineral oil on all sides prior to the concrete being poured into them. Using a tamping rod, the concrete was poured into the molds in three layers. A trowel was then used to create a smooth, hard, and dense surface. The molds were taken out after a day and, if needed, were left in a curing tank for 7, 14, and 21 days.

3.5.1.4. Curing of specimens

After casting the specimens, these were marked for identification using the two variables taking in consideration their FA percentage and their curing time, after this, all specimens were removed from and placed in water for curing. The process of curing in the basin can be identified in the *Figure 3. 10* below.

Figure 3. 10: during curing process

3.5.2. Tests conducted

These were several tests carried out to ascertain the compressive strength and consistency in relation to the water ratio and assess if they effectively fulfilled the study's requirements.

3.5.2.1. Compressive strength test

The specimens were tested by compression testing machine after 7, 14 and 21days curing. The load was applied gradually till the specimens failed. Concrete's compressive strength can be calculated by dividing the load at failure by the specimen area.

- **Objectives**

A compressive strength test was carried out to determine the load bearing capacity of cubes. At the 7, 14, and 21-day curing ages, a compressive strength test using a testing machine was conducted in compliance with (BS: 516-1959). Two cubes were crushed in each day of the above stated days for each mix of both materials (sand- cement and PFA sand-cement cubes) respectively and the average compressive strength was measured for each cube mix specifications.

- **Apparatus used**

The specimen's behavior under a compressive load was measured using a compressive testing equipment to ascertain how the cube responds when crushed or compressed, as indicated in the following *Figure 3. 11*.

Figure 3. 11: Performing compressive strength test

- **Procedures**

Specimens were tested with the centroid of their bearing surfaces aligned vertically with the center of thrust of the spherically seated steel bearing cubes of the testing machine. The machine's control was then modified as needed to give the moving head a uniform rate of movement so that the remaining load is applied in less than or more than two minutes. The load was applied at any convenient rate up to half of the anticipated maximum load.

A masonry unit's (cube's) compressive strength was calculated by dividing its gross sectional area in square millimeters by the maximum force at specimen failure in newtons.

3.5.2.2. Slump test

- **Objective**
- The concrete slump test is an empirical procedure used to gauge how workable freshly mixed concrete is or how much energy is needed overall to operate with this combination (Yu *et al.*, 2011). The test establishes the energy needed for the concrete work at a particular water cement ratio and evaluates the consistency of the concrete in that particular batch.
- **Test equipment**

1) The slump cone at standard dimensions (100 mm top diameter x 200 mm bottom diameter x 300 mm height)

2) Long bullet nosed metal rod (600 mm) long, diameter (16 mm)
3) Measuring graduated and readable ruler.

- **Procedure of Slump test**

The processes listed below are taken during a slump test:

- The interior surface of the mold is first cleared of all debris, moisture, and previous concrete sets.
- Next, set the mold onto the non-absorbent, firm, and flat horizontal surface.
- After that, fresh concrete is poured into the mold in four stages, leveling the top surface with a trowel and taping each layer 25 times with a tape rod.
- Then the mould is slowly pulled in vertical and removed from concrete, so as not to disturb the concrete cone.
- This free concrete deforms the entire surface to subside due to the effect of gravity.
- There is a SLUMP of concrete due to the peripheral concrete subsidence.
- The "slump value of concrete" is the height difference, expressed in millimeters, between the mold cone and subsidence concrete. (cementconcrete.org, Slump Test of Concrete, slump cone for Workability – Procedure, Apparatus, 2019).

Recorded slump value of a sample is = ……… mm

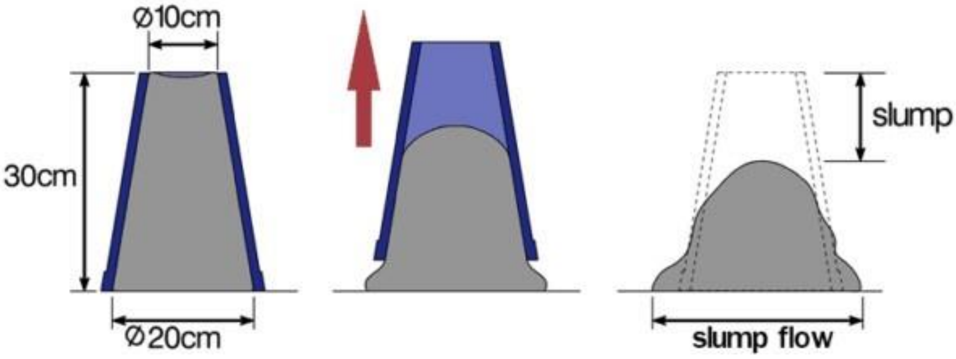

Figure 3. 12: Slump Test of concrete

The manual codes that are utilized are BS EN 12350-2:2009 - Testing Fresh Concrete, Slump Test and (ASTM C 143) or (AASHTO T 119):

Slump value = cone height – sample height

The recommended range for slump value depends on the work condition and requirements for a concrete batch. Note that the slump value depends on water cement ratio the mix ratio, admixtures, temperature, the nature and properties of materials used.

3.5.3. Interview

In some cases, I conducted construction site that makes in-situ concrete and ask them some questions based on what I was observing in other to help me with my research. This also facilitated my laboratory work.

3.6. Data analysis and interpretation

The collected data is analysed using both statistical and graphical methods. The following analytical tools and software are utilized:

3.6.1. Microsoft Excel

It is utilized for basic data entry, descriptive statistics, and graph plotting to show material attributes, cost variations, and compressive strength trends.

3.7. Consideration of Engineering ethics

The materials, research design, data collection techniques, and analytical tools for examining fly ash's application in concrete as a cement supplement have all been described in this chapter. The results are guaranteed to be credible and valid from a scientific standpoint by using both statistical software and physical testing. The outcomes of these techniques will be shown and their consequences will be covered in the upcoming chapter.

We must reduce our output of greenhouse gases. This was accomplished by making sure the concrete technique selected reduces emissions of carbon dioxide, a strong greenhouse gas. In addition, we took action to reduce waste generation and stop the buildup of dust particles in the atmosphere, safeguarding the atmosphere overall (Li *et al.*, 2021).

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0. Chapter overview

The findings that were acquired are presented in this chapter. The results were about to achieve the four previously mentioned specific objectives. These results were obtained by going throughout the methodologies and using the appropriate materials to perform required tests on the manufactured concrete. Some of my photos that were taken during the laboratory, can be seen in APPENDI.

4.1. Specimen preparation and curing

The concrete cubes (control specimens) of size 150mmx150mmx150mm were cast by using conventional aggregates. This was labeled as concrete.

There was another batch of concrete cubes, made from a concrete mixture where cement was partially replaced by different percentages of peat coal fly ash respectively. This was called concrete.

Figure 4. 1: Specimen boxes ready for test after curing

For each mix, 150mm size cubes shown in the *Figure 4. 1* above, at three days old, there were cast in order to measure their compressive strength. The same cubes used for compressive strength. Here after 3 days of curing in water bath specimen must be tested.

4.2. Slump test

The fresh concrete's workability (measured in terms of slump) was determined for each combination. Slump test protocol was followed in compliance with BS 1881: Part 102: 2011.

For concrete, the water to cement ratio was maintained at 0.5. With different mixtures in concrete, the proportions of peat coal fly ash which partially replaced cement in proportions of 0%, 5%, 15% and 20% of peat coal fly ash and cement respectively. The slumps of these concretes were as follows:

Table 4. 1: Slump of concrete mixtures

SN	Designation	Slump in mm
1	Normal concrete	**130**
2	Concrete with 5% peat coal fly ash and 95% of cement	**125**
3	Concrete with 10% peat coal fly ash and 90% of cement	**95**
4	Concrete with 15% peat coal fly ash and 85% of cement	**70**
5	Concrete with 20% peat coal fly ash and 80% of cement	**45**

The following figure shows that the slump kept on reducing as the percentage concentration of peat coal fly ash was being increased.

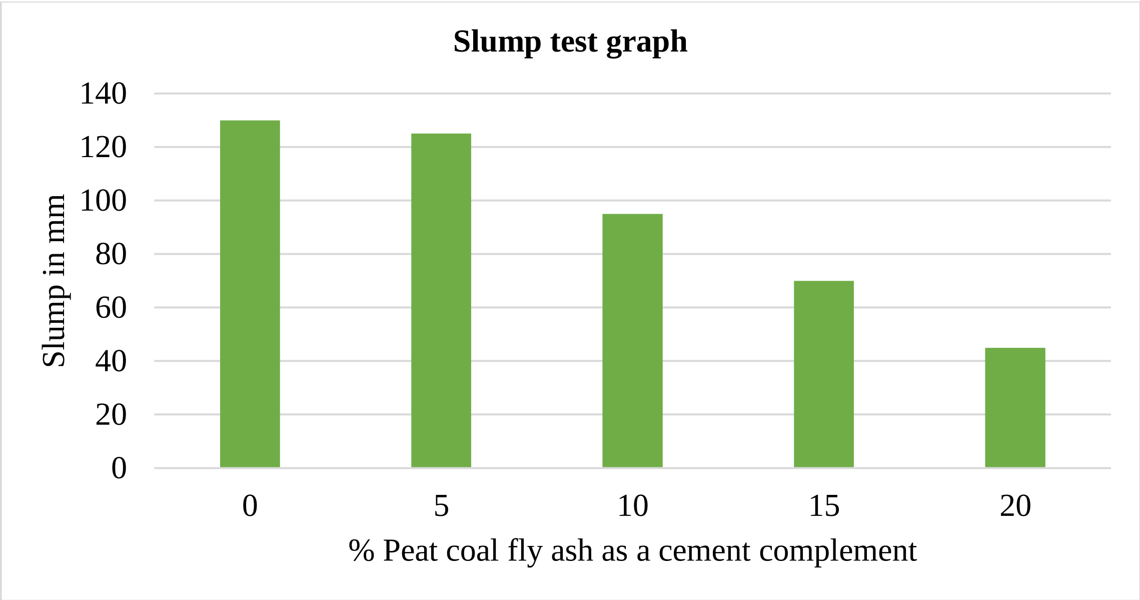

Figure 4. 2: Slump test graph

The amount of water used was kept the same for all mixtures. As a result of partially substituting peat coal fly ash for cement, it was possible to detect that the slump decreased as well. As the quantity of peat coal fly ash, the slump was decreasing progressively, yet the amount of the water was kept the same W/C=0.5.

4.3. Casting concrete specimen

Every specimen was cast in two layers, and a steel rod was used to condense them. Vibration could stop when air bubbles appear on the surface. They were left in the mould in the laboratory at 20 to 25^oC respectively. The specimens were tested immediately after being removed from the water bath in 3 days.

4.4. Test of compressive strength

Prior to the compressive strength at the age of three days, 150mm cubes were crushed in line with BS 1881: Part 116: 2011 to determine the compressive strength. Three average values were obtained.

The most important factor is the concrete's compressive strength. It shows the intended usage for the particular concrete. In addition to their qualities, the percentage of constituents (materials) employed directly affects the resulting compressive strength. During the mixing process, the variables were the cement ratio and the proportion of fly ash from peat coal. Tables display each mixture's compressive strength after three days.

We should have tested after 7, 14, and 21 days. Due to the lack of availability of Civil Engineering laboratory that limited us to make full experiments on compressive strength tests. According to the availability of time we made a compressive strength tests on 3 days which was possible to make results as shown in tables below.

Table 4.2: Normal concrete compressive strength

	3 days	
Area (Mm^2)	**Force (N)**	**Strength (MPa)**
22500	394400	17.528

Table 4.3: Concrete compressive strength with 5% replacement

	3days	
Area (Mm^2)	**Force (N)**	**Strength (MPa)**
22500	401200	17.831

Table 4.4: Concrete compressive strength with 10% replacement

	3days	
Area (m^2)	**Force (KN)**	**Strength (MPa)**
22500	406200	18.053

Table 4.5: Concrete compressive strength with 15% replacement

	3days	
Area (Mm^2)	**Force (N)**	**Strength (MPa)**
22500	374700	16.653

Table 4.6: Concrete compressive strength with 20% replacement

	3days	
Area (Mm^2)	**Force (N)**	**Strength (MPa)**
22500	373200	16.586

The general observation about these results were summarized as follows in the table below.

Table 4.7: Comparison of compressive strength of all concrete grades

Designation	**Compressive strength in 3 days (MPa)**
Normal concrete	17.528
Concrete with 5% of peat coal fly ash and 95% of cement	17.831
Concrete with 10% of peat coal fly ash and 90% of cement	18.053
Concrete with 15% of peat coal fly ash and 85% of cement	16.653
Concrete with 20% of peat coal fly ash and 80% of cement	16.586

These results were then represented graphically to get a better understand and clear view of how concrete compressive strength changed with changement in percentage concentration of peat coal fly ash replacing cement.

Based on figure representation, Compressive strength presents Y-axis and Percentages of peat coal fly ash presents X-axis.

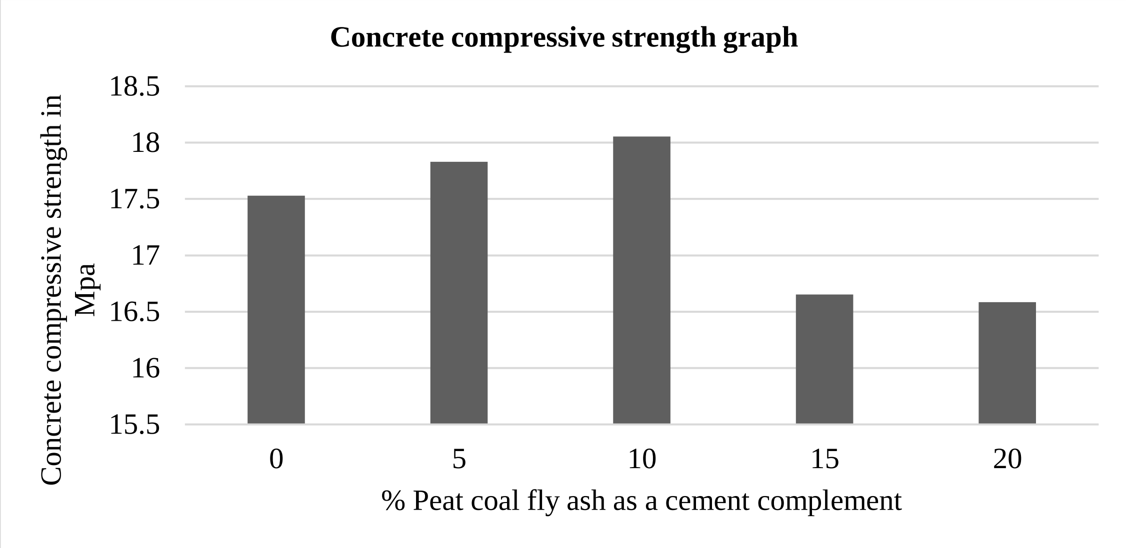

Figure 4. 3: Concrete compressive strength with varying % fly ash

After three days, the compressive strength of regular concrete was 17.528 MPa. At 3 days old, the compressive strength values were 17.831 MPa with 5% replacement. Three days later, the compressive strength values with 10% replacement were 18.053 MPa; 3 days later, the compressive strength values with 15% replacement were 16.653 MPa; and three days later, the compressive strength values with 20% replacement were 16.586 MPa.

In conclusion, 10% of peat coal fly ash is the ideal proportion to use for substituting peat coal fly ash for cement in concrete, according to our research.

4.5. Pricing and cost estimation of concrete

The process of evaluating the cost of concrete and its corresponding reduction when there is a partial replacement of cement by another binder known as peat coal fly ash is being undertaken with the goal of this project, which is to try and make concrete work more inexpensive. There contains limiting the approximation mainly the required strength of concrete. Costs in this study were estimated based on the best and appropriate estimates and assumptions.

Cost of concrete without PFA = 350,000rwf

Reduction on concrete made by 10% of peat coal fly ash and 90% of cement:

1m^3 of concrete has 8 bags of cement which is equal to 400kg

1 bag of cement of 50kg values 13000frw, the amount for 8bags is 104000frw

10% of peat coal fly ash in concrete replace cement = 400x10/100= 40kg

One bag of peat coal fly ash of 50kg values 4000frw

20kg of peat coal fly ash cost = 4000x40/50 = 3200frw

Amount of money that will be saved = 104,000-3200=100800frw

This means, at 10% of peat coal fly cost that will be saved is equal to 3,200frw.

While the peat coal fly ash is a waste material that can be used to replace partially cement in concrete, it can reduce the cost of cement which makes it easy for low- and middle-income earners to own their houses.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

We draw the following conclusions from our experimental study on the compressive strength and slump test of concrete that uses peat coal fly ash in place of some of the cement: because peat coal fly ash is a waste product that can be used in place of some of the cement in concrete, it lowers the cost of cement, making it easier for low- and middle-class people to own their homes.

The compressive strength of concrete cubes increased as the percentage of peat coal fly ash increased, according to the data. However, for every % of peat coal fly ash replacement, the compressive strength rose with the amount of curing days. This experiment demonstrates that 10% of peat coal fly ash is the ideal amount, and after three days, its relative compressive strength is 18.053 MPa.

According to the experimental results, the best peat coal fly ash to utilize as a cement supplement material in building is this one, which lowers the price of one meter three of concrete from three50,000 to three48,400 Rwf.

By developing further information, abilities, and experience in the field of study, the research's goals were met, and a technical resource for construction was developed.

5.2. Recommendations

- ✓ By the end of this project, we recommend people to adopt the peat coal fly ash material in their concrete works because it will be profitable and used.
- ✓ Material optimization will be possible with a deeper comprehension of the attributes. The information gained would result in ideal, cost-effective designs.
- ✓ It is recommended to conduct durability tests on concrete cubes that contain fly ash from peat coal in place of some of the cement.
- ✓ Encourage the use of indigenous materials in the creation of concrete, such as fly ash and peat coal, for the purpose of pozzolana.
- ✓ One way to reduce environmental dangers like air, water, and land pollution is to use fly ash from peat coal as a cement supplement in small amounts. This is in line with the policy of using renewable energy sources.

REFERENCES

1) Ahmadi, B.H. (2000) ‘Initial and final setting time of concrete in hot weather’, *Materials and Structures/Materiaux et Constructions*, 33(8), pp. 511–514. Available at: https://doi.org/10.1007/BF02480528.
2) Alaj, A., Krasniqi, N. and Numao, T. (2024) ‘Effect of Non-Class Fly Ash on Strength Properties of Concrete’, *Civil Engineering Journal (Iran)*, 10(3), pp. 689–698. Available at: https://doi.org/10.28991/CEJ-2024-010-03-02.
3) Aliansyah, Z.J. and Firdaus, F. (2024) ‘The Effect of Fly Ash Substitution in 3 Brands of PCC Cement on The Compressive Strength f Concrete’, *Jurnal Teknik Industri: Jurnal Hasil Penelitian dan Karya Ilmiah dalam Bidang Teknik Industry*, 10(1), p. 51. Available at: https://doi.org/10.24014/JTI.V10I1.25829.
4) Amat, R.C. *et al.* (2024) ‘Effects of coal fly ash as partial replacement for cement towards concrete properties’, *IOP Conference Series: Earth and Environmental Science*, 1369(1). Available at: https://doi.org/10.1088/1755-1315/1369/1/012031.
5) Brooks, J.J., Megat Johari, M.A. and Mazloom, M. (2000) ‘Effect of admixtures on the setting times of high-strength concrete’, *Cement and Concrete Composites*, 22(4), pp. 293–301. Available at: https://doi.org/10.1016/S0958-9465(00)00025-1.
6) Bui, V.B. *et al.* (2023) ‘Accuracy Evaluation of Slump and Slump-Flow Test for 3D Concrete Printing with the Kinect v1’, *Lecture Notes in Mechanical Engineering*, pp. 535–543. Available at: https://doi.org/10.1007/978-3-031-31824-5_62.
7) Carmal, J. (2024) ‘Experimental Investigation on Ductility in Fly Ash Aggregate Concrete’, *International Journal of Innovative Research in Advanced Engineering*, 11(05), pp. 492–499. Available at: https://doi.org/10.26562/IJIRAE.2024.V1105.08.
8) Castro Pérez, J. and Roesler, J. (2022) ‘Setting time in Roller-Compacted Concrete (RCC)’, *e-Journal of Nondestructive Testing*, 27(9). Available at: https://doi.org/10.58286/27227.
9) Choi, S.J., Lee, S.S. and Monteiro, P.J.M. (2012) ‘Effect of Fly Ash Fineness on Temperature Rise, Setting, and Strength Development of Mortar’, *Journal of Materials in Civil Engineering*, 24(5), pp. 499–505. Available at: https://doi.org/10.1061/(ASCE)MT.1943-5533.0000411.
10) Chu, H.H. *et al.* (2021) ‘Sustainable use of fly-ash: Use of gene-expression programming (GEP) and multi-expression programming (MEP) for forecasting the

compressive strength geopolymer concrete', *Ain Shams Engineering Journal*, 12(4), pp. 3603–3617. Available at: https://doi.org/10.1016/J.ASEJ.2021.03.018.

11) Das, B.B. and Pandey, S.P. (2011) 'Influence of Fineness of Fly Ash on the Carbonation and Electrical Conductivity of Concrete', *Journal of Materials in Civil Engineering*, 23(9), pp. 1365–1368. Available at: https://doi.org/10.1061/(ASCE)MT.1943-5533.0000298.

12) Elsharawy, M. and Saiful Islam, A.B.M. (2024) 'Comparative study of lightweight and conventional concrete materials in buildings on weak soil of coastal region in KSA', pp. 194–200. Available at: https://doi.org/10.1049/ICP.2024.0924.

13) Garg, R.B. and Singh, G. (2024) 'Green Manufacturing and Evaluation of Concrete with Improved Mechanical and Thermal Properties Using OPC Grade 43 and Fly Ash', *Lecture Notes in Civil Engineering*, 464, pp. 267–278. Available at: https://doi.org/10.1007/978-981-97-0910-6_22.

14) Gülşan, M.E. *et al.* (2019) 'Development of fly ash/slag based self-compacting geopolymer concrete using nano-silica and steel Fiber', *Construction and Building Materials*, 211, pp. 271–283. Available at: https://doi.org/10.1016/J.CONBUILDMAT.2019.03.228.

15) Kassa, B.R., Kanali, C. and Ambassah, N. (2019) 'Engineering Properties of Polyethylene Terephthalate Fibre Reinforced Concrete with Fly Ash as a Partial Cement Replacement', *Civil and Environmental Research* [Preprint]. Available at: https://doi.org/10.7176/CER/11-6-05.

16) Lou, H., Ma, C. and Hong, Q. (2024) 'Influence of Fly Ash and Basalt Fibers on the Properties of Recycled Pervious Concrete', *Lecture Notes in Civil Engineering*, 603 LNCE, pp. 62–75. Available at: https://doi.org/10.1007/978-981-97-5814-2_6.

17) Luan, C. *et al.* (2021) 'Practical prediction models of tensile strength and reinforcement-concrete bond strength of low-calcium fly ash geopolymer concrete', *Polymers*, 13(6). Available at: https://doi.org/10.3390/POLYM13060875.

18) Mahajan, L., Mahadik, S. and Bhagat, S.R. (2020) 'Investigation of Fly Ash Concrete by Slump Cone and Compaction Factor Test', *IOP Conference Series: Materials Science and Engineering*, 970(1). Available at: https://doi.org/10.1088/1757-899X/970/1/012011.

19) Mousavinezhad, S. and Newtson, C.M. (2024) 'Replacing fly ash with a natural pozzolan in normal strength concrete and ultra-high performance concrete', *MATEC*

Web of Conferences, 396, p. 02007. Available at: https://doi.org/10.1051/MATECCONF/202439602007.

20) Muthusami, Y. *et al.* (2024) 'Influence of fly ash on rheological behaviour of HVFA concrete', *MATEC Web of Conferences*, 400, p. 01001. Available at: https://doi.org/10.1051/MATECCONF/202440001001.
21) Prem Kumar, V. *et al.* (2024) 'Experimental investigation on utilization of substitute building materials in concrete using neural networks', *E3S Web of Conferences*, 529. Available at: https://doi.org/10.1051/E3SCONF/202452901028.
22) Presa Madrigal, L. *et al.* (2024) 'Cost-Effective Temperature Sensor for Monitoring the Setting Time of Concrete', *Applied Sciences (Switzerland)*, 14(11). Available at: https://doi.org/10.3390/APP14114344.
23) Procházka, L. and Boháčová, J. (2020) 'Effect of admixtures on durability characteristics of fly ash alkali-activated material', *Emerging Science Journal*, 4(6), pp. 493–502. Available at: https://doi.org/10.28991/ESJ-2020-01247.
24) Punurai, W. *et al.* (2018) 'Mechanical properties, microstructure and drying shrinkage of hybrid fly ash-basalt fiber geopolymer paste', *Construction and Building Materials*, 186, pp. 62–70. Available at: https://doi.org/10.1016/J.CONBUILDMAT.2018.07.115.
25) Raj, B.S. and Rao, M.K. (2023) 'Flexural Performance of Sustainable Fly Ash Based Concrete Beams', *IOP Conference Series: Earth and Environmental Science*, 1130(1). Available at: https://doi.org/10.1088/1755-1315/1130/1/012021.
26) Rao, K.G. (2023) 'Experimental Study on Partial Replacement of Cement by GGBS and Fly Ash in Conventional Concrete', *International Journal for Research in Applied Science and Engineering Technology*, 11(11), pp. 1566–1575. Available at: https://doi.org/10.22214/IJRASET.2023.56713.
27) Saha, S., Saha, P. and Talluri, N. (2022) 'Effects of quality of water on the setting times and compressive strength of concrete', *Materials Today: Proceedings*, 60, pp. 378–383. Available at: https://doi.org/10.1016/J.MATPR.2022.01.252.
28) Shanmugapriya, J. and Chinnaraju, K. (2024) 'Transport Properties of Internally Cured Self Compacting Concrete with Fly Ash', *Cement Wapno Beton*, 29(1), pp. 2–15. Available at: https://doi.org/10.32047/CWB.2024.29.1.1.
29) Shen, D. (2024) 'Early-age Cracking Control on Concrete with Fly Ash', *Early-age Cracking Control on Modern Concrete*, pp. 91–124. Available at: https://doi.org/10.1007/978-981-97-1495-7_4.

30) Tariq, H. *et al.* (2022) ‘Mechanical Performance of Polymeric ARGF-Based Fly Ash-Concrete Composites: A Study for Eco-Friendly Circular Economy Application’, *Polymers*, 14(9). Available at: https://doi.org/10.3390/POLYM14091774.
31) Topark-Ngarm, P., Chindaprasirt, P. and Sata, V. (2015) ‘Setting Time, Strength, and Bond of High-Calcium Fly Ash Geopolymer Concrete’, *Journal of Materials in Civil Engineering*, 27(7). Available at: https://doi.org/10.1061/(ASCE)MT.1943-5533.0001157.
32) Uyanik, M.E. (2019) ‘An investigation of non-destructive testing techniques for concrete structures.
33) Wang, X. *et al.* (2021) ‘Development of water retentive and thermal resistant cement concrete and cooling effects evaluation’, *Materials*, 14(20). Available at: https://doi.org/10.3390/MA14206141.
34) Xu, J. *et al.* (2023) ‘Final Setting Judgment and Safety Evaluation of Mass Concrete Based on Strain Monitoring’, *Applied Sciences (Switzerland)*, 13(4). Available at: https://doi.org/10.3390/APP13042283.
35) Yu, X. *et al.* (2011) ‘Influence of testing methods on setting time of foam concrete’, *Advanced Materials Research*, 177, pp. 514–517. Available at: https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMR.177.514.

APPENDICES

Appendix 1) Measuring the ingredients that will be used to make concrete

Appendix 2) Proceeding with concrete setting time test

Appendix 3) Carrying out slump test