Investigation on the Combined Effect of Recycled Polypropylene Fibers and Fly Ash as Partial Cement Replacement for Concrete Production

Abel Mequanent Merhatsion

A Thesis Submitted to the Department of Civil Engineering

School of Civil Engineering and Architecture

Presented in partial fulfillment of the Requirement for the Degree of master's in civil engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

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Adama, Ethiopia

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DECLARATION

I here by declare that this thesis entitled "Investigation on the Combined Effect of Recycled Polypropylene Fibers and Fly Ash as Partial Cement Replacement for Concrete Production" is my own work and has not been submitted to any university for similar purposes. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Investigation on the Combined Effect of Recycled Polypropylene Fibers and Fly Ash as Partial Cement Replacement for Concrete Production" prepared under my guidance by Mr. Abel Mequanent Merhatsion submitted in partial fulfilment of the requirements for the degree of Mater's of Science in civil engineering (Specialization in Construction Engineering and Management).

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Fikreyesus Demeke (PhD)	______________________	________________
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APPROVAL PAGE

I, the advisor of the thesis entitled "Investigation on the Combined Effect of Recycled Polypropylene Fibers and Fly Ash as Partial Cement Replacement for Concrete Production" and developed by Mr. Abel Mequanent Merhatsion, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Mr. Abel Mequanent Merhatsion have read and evaluated the thesis entitled "Investigation on the Combined Effect of Recycled Polypropylene Fibers and Fly Ash as Partial Cement Replacement for Concrete Production" and examined the candidate during the open defence. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Construction Engineering and Management.

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ABSTRACT

Nowadays, ongoing global research focuses on developing high-performance concrete through intelligent material use, incorporating additive materials, and advancing innovative eco-friendly construction practices. The aim of this study paper is to investigate the combined effect of using fiber made from a recycled polypropylene post-consumer packaging plastic material as an alternative to traditional fibers and partial cement replacement with fly ash on ordinary portland cement concrete. The study discusses the experimental investigation works on both control and modified concrete's workability, compressive strength, split tensile strength, flexural strength, durability, and internal microstructure investigation work using scanning electron microscopy (SEM) analysis. The experiment includes three different contents of the recycled polypropylene fibers (0.5 , 1 and 1.5 wt.% of cement) and three different contents of the fly ash (0 ,10 and 20 wt.% of cement). The strength, durability and scanning electron microscopy (SEM) image analysis work of the samples were tested after 7 and 28 days. Based on the findings of the study, adding fly ash improved the workability by enhancing the flowability of the concrete. The compressive strength, split tensile strength and flexural strength has been improved notably. A Mixture with 10% fly ash replacement and 1% PP fiber exhibited the highest compressive strength, split tensile strength and flexural strength among all the combinations which is an increase in 39.99%, 52.73% and 74.31% respectively compared to control mix. The SEM image also showed distinct differences compared to the control C25 concrete. The modified concrete exhibited a densely compact microstructure, reduced size of pores and number cracks. The durability property test was also conducted using water absorption test and the sulfate attack test using 5% sodium sulfate solution. Both durability test shows that the combined effect of fly ash and PP fibers enhances the concrete's resistance to water absorption and sulfate attack, providing a more effective barrier against the ingress of such solutions.

Key words: Fibre reinforced concrete (FRC); Recycled Polypropylene Fiber (R-PPF); Fly Ash (FA)

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ACRONYMS

ABS	Acrylonitrile-butadiene-styrene
CCPs	Coal combustion products
DEF	Delayed Ettringite Formation
ESP	Electrostatic precipitator
FA	Fly ash
FRC	Fiber-reinforced concrete
FGD	Flue gas desulfurization
FRPCP	Fiber-reinforced precast concrete panel
FRC	Fiber-reinforced concrete
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
OPC	Ordinary portland cement
PP	Polypropylene
PPC	Portland Pozzolana Cement
PS	Polystyrene
PE	Polyethylene
PVC	Polyvinychloride
PA6	Poly (E-caprolactame)
PTFE	Polytetraflourethylene
R-PPF	Recycled polypropylene fiber
PET	Polyethylene terephthalate
SEM	Scanning Electron Microscopy
SSD	Saturated surface dry

LIST OF CHEMICAL FORMULAS

Formulas	Name of Chemical Compound
$2CaO.SiO_2$	Dicalcium silicate
$3CaO.SiO_2$	Tricalcium silicate
$3CaO.Al_2O_3$	Tricalcium aluminate
$CaSO_4.2H_2O$	Gypsum
$Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$	Ettringite
$3CaO\cdot Al_2O_3\cdot CaSO4\cdot 12H_2O$	Mono sulfate aluminate hydrate
$4CaO.Al_2O_3.Fe_2O_3$	Tetra calcium aluminoferrite

CHAPTER ONE

1 INTRODUCTION

1.1 General Background

New building materials are being developed worldwide with great effort due to technological improvement. It is now widely acknowledged that economic growth in construction depends on the intelligent use of materials and continuous material development rather than intense structural analysis and refinement. Many studies worldwide attempt to develop high-performance concrete by incorporating other materials and additives into the concrete mix. Even though concrete has some drawbacks, it is still one of the most widely used construction materials due to its versatility, durability, and strength. However, conventional concrete production using Ordinary Portland Cement (OPC) is associated with significant environmental impacts, including high carbon dioxide emissions. As a result, researchers and practitioners have been exploring sustainable alternatives and modifications to traditional concrete mixtures to address these concerns.

One such approach is the incorporation of recycled polypropylene (PP) plastic fibers, which can enhance concrete's mechanical properties and durability while utilizing waste materials. For reinforcing concrete structures, polypropylene plastic fibers, made from post-consumer goods, provide an environmentally responsible option. Previous studies have shown their potential to improve concrete's crack resistance, impact resistance, and ductility (Smith et al., 2018; Lee et al., 2020).

Another sustainable practice involves introducing supplementary cementitious products such as fly ash, a byproduct of coal combustion in power plants. Fly ash is known to improve concrete's workability, long-term strength, and durability. Its utilization reduces the consumption of Ordinary Portland cement (OPC), thus lowering carbon dioxide emissions and decreasing the demand for virgin materials (ACI Committee 232, 2002; ASTM C618, 2017).

While both recycled PP fibers and fly ash individually offer better environmental and performance benefits, their combined effect on concrete properties is an area that warrants further investigation. By understanding the synergistic impact of these two favorable additives, valuable insights can be gained into optimizing concrete mix designs for environmentally friendly and high-performance construction materials. Therefore, this study aims to investigate the combined effect of recycled PP fibers and partial cement replacement with fly ash on the properties of OPC concrete.

1.2 Statement of the problem

The use of sustainable construction materials and techniques has become increasingly important in the field of civil engineering. Concrete, one of the most widely used construction materials, presents an opportunity for innovation and improvement to enhance its performance and sustainability. Unlike other structures, these materials also have some downsides; they are weak in tension, have poor bending resistance, have low failure strain, and tend to fracture in a relatively brittle fashion, as the elasticity or deformation capacity of concrete is limited. In such structures, brittle failure results from inelastic deformation, which can be minimized if the concrete behaves flexibly so that the member can absorb and dissipate a large amount of energy (Thombare et al., 2018). The ease with which micro cracks may be formed from the outside to the inside causes the concrete to become more porous. Concrete's interior is readily penetrated by water or other damaging ions, which hastens the concrete's degeneration (Hussain et al., 2020).

In recent years, promising approaches which improve concrete properties and environmental sustainability have gained attention, like the incorporation of plastic fibers and the partial replacement of cement with fly ash. While several studies have individually investigated the effects of these two techniques on concrete properties, there needs to be more comprehensive research that explores their combined effect on the properties of Ordinary Portland Cement (OPC) concrete. This study aims to bridge this knowledge gap by examining how the introduction of recycled PP fibers and the partial replacement of cement with fly ash influence various concrete properties, such as strength, durability, and workability.

The first aspect of the problem to be addressed is the impact of recycled PP fibers on concrete properties. Adding fibers to concrete can present challenges in mixing and placement. Fibers tend to clump together, requiring proper mixing techniques to achieve uniform distribution throughout the mixture. Improper mixing can result in inadequate dispersion of fibers, leading to inconsistent concrete performance and potential deterioration in strength. Additionally, unideal insertion fibers can reduce the workability of concrete, making it stiffer and less fluid. This reduction in workability can make it more challenging to handle and place the concrete, requiring additional effort during the pouring, leveling, and finishing stages. It is essential to carefully consider the fiber type and dosage to ensure that the desired reinforcement properties are achieved without compromising the overall strength and performance of the concrete.

The other issue in the study relates to the influence of partial cement replacement with fly ash. Previous research has highlighted the positive influence of fly ash on concrete, such as improved workability, reduced permeability, and enhanced long-term durability. However, limited attention has been given to examining how the combined use of fly ash and recycled PP fibers affects the concrete matrix. Investigating the combined effect of these materials will shed light on their compatibility, potential interactions, and overall contribution to concrete performance. In general, the study aimed in designing sustainable concrete mixtures that offer enhanced properties while reducing the environmental impact.

1.3 Objectives of the study

1.3.1 General objective

The main objective of the study is to investigate the combined effect of recycled polypropylene fibers and partially replacing cement with fly ash based on ordinary portland cement concrete.

1.3.2 Specific objectives

The specific objectives of the study is : -

- To characterize materials required for the investigation of the experimental concrete.
- To investigate the workability property of the fresh experimental concrete mix.
- To investigate the compressive, flexural, and split tensile strengths of both control and experimental concrete mix of recycled polypropylene fibres and fly ash.
- To examine the combined effects of R-PPF and FA on the durability property and internal microstructure of the concrete in comparison to control concrete.

1.4 Significance of the study

Concrete is regarded to be a highly fragile material. Increased brittleness is a side effect of increased strength. This might be brought on by a lack of bonding and weak tensile strength in the transition zone of the cement matrix, which prohibits using high-strength concrete under static and, particularly, dynamic loading (Brandt, 2008). Therefore, ductility augmentation must be considered a vital problem in concrete science. One method for increasing the elasticity and resilience of concrete structures is possible due to the fibers that have been added to concrete (Song et al.,2005), which offer protection from dynamic loads brought on by impact, fatigue, and earthquakes. Concrete's ability to absorb energy increases by adding fibers, making the structure more ductile. Steel, carbon, or polymers are the major elements used to make fibers (Ghavami, 2005). According to Shah et al., (2011) research, steel, nylon, and polypropylene plastic fibers may be used to boost reinforced concrete's shear and tensile strength. Concrete’s mechanical performance may be enhanced by adding polypropylene without increasing its density (Yewet al.,2015). The plastic fiber polypropylene has received the greatest attention from researchers due to its low cost, remarkable durability, and improved shrinkage cracks (Toutanji,1999). Additionally, it has been noted that the technical characteristics of concrete, particularly tensile capacity, are marginally improved by nylon and propylene plastics (Yap et al.,2013). The concrete composite may also generate a three-dimensional random distribution network structure when introducing polypropylene plastics fiber, preventing micro-cracks formation (Qin et al.,2019). In addition, the by-product of coal combustion in power plants, fly ash also contributes the improvements in concrete performance. According to studies by Dutta and Roy (2020) and Mindess et al., (2003), fly ash can enhance the workability, strength, durability, and resistance to chemical attacks of concrete. The pozzolanic properties of fly ash allow for improved hydration, reduced heat generation, and reduced permeability of the concrete matrix. Additionally, fly ash aids in the reduction of alkali-silica reactivity and provides increased resistance to sulfate attack.

In environment perspective, the improper waste disposal of plastics leads to severe environmental concerns, such as human health hazards, effects on animal life, water pollution (Haward, 2018), air pollution, soil impurities and other concerns (Cooper et al.,2017 & Lavers et al., 2019). Since plastics are soft, flexible, durable, non-corrosive, acid resistant and have high thermal and electrical insulation features, it makes them the safest, easiest to produce, and cheapest solution for the different packaging industries (Akcaözoğlu, 2010). Besides, most plastic products are single use, which produces various types of plastic garbage that take hundreds of years to disintegrate (Huysman et al, 2017). The widespread use of such plastics in most daily activities increases the volume of plastic waste. So it would be wise to recycle and incorporate such materials as a construction component. Hence, both polymer plastic modification and fiber reinforcement have been used successfully used in practice to alleviate such difficulties (Thombare et al., 2018). Fly ash also poses a potential health and environmental concerns if it’s not disposed properly too. Firstly, its fine particulate nature allows for easy dispersal in the air, leading to the inhalation of toxic constituents by workers and nearby communities. According to a study by Maiti et al., (2019), inhaling fly ash particles can result in respiratory disorders and cardiovascular diseases. Secondly, the leaching of heavy metals from fly ash can contaminate soil and ground water, posing a threat to ecosystems and human health. Research conducted by Ghosh et al., (2018) demonstrated elevated levels of heavy metals which are highly toxic and damaging to the environment in the vicinity of fly ash disposal sites. Consequently, proper handling, disposing, and mitigating fly ash's adverse effects are crucial to minimize potential health risks and environmental contamination (Chatterjee et al., 2019).

Therefore, the introduction of a new application of scientific knowledge and practices to use fly ash and recycled polypropylene fibers in concrete presents a feasible approach towards achieving durable and high-performance structures, while contributing to the overall sustainability of the construction industry.

1.5 Scope of the study

The scope of the research is to investigate fresh and hardened concrete properties of the combined effect of the composite concrete made from recycled polypropylene fibers and partial cement replacement with fly ash on ordinary portland cement C-25 concrete. The compressive strength, flexural strength, split tensile strength, durability property and internal microstructure analysis work using scanning electron microscopy (SEM) was conducted.

1.6 Limitations

Generalizability: The findings of this study may be limited in terms of generalizability to different concrete mixtures and conditions. The specific combination of recycled polypropylene fibers, fly ash, and OPC cement explored in this study may yield different results when different materials or proportions are used.

Time and Resources: The scope of this study may be constrained by the available time, budget, and resources. This includes the specific dosage or percentage of recycled polypropylene fibers used in the composite concrete and the certain range of cement replacement with fly ash. Additionally, the research might be limited to a specific type of ordinary portland cement and concrete (C-25) and may not encompass other types or grades of concrete.

External Factors: The study did not account for the influence of external factors such as temperature, humidity, and environmental conditions, which can affect the performance of concrete in real-world applications. These factors may limit the applicability of the findings to specific environments.

1.7 Organization of the thesis

This thesis is organized into five main chapters, each serving a specific purpose to ensure a comprehensive exploration of the research topic. The organization of the thesis is as follows:

The first chapter provides an overview of the research topic, setting the context for the study. It begins with a general background, highlighting the importance and relevance of the research area. The statement of the problem identifies the specific research gap that this study aims to address. The objectives of the study outline the general and specific goals to be answered. The significance of the study highlights the potential contributions and implications of the research findings. Lastly, the scope and limitation of the study defines the boundaries and constraints of the research.

The second chapter presents a comprehensive review of the existing literature related to the research topic. It begins with an introduction that sets the stage for the literature review. The theoretical literature review examines the key concepts, definitions, and properties of materials relevant to the research topic. The empirical literature review analyzes previous empirical studies and research findings in the field. The chapter also identifies any research gaps or unanswered questions in the literature, highlighting the need for the current study.

The third chapter outlines the research design, materials, and methods employed in this study. It starts with an introduction that provides an overview of the chapter. The research design section describes the overall approach and structure used in the study. The materials section outlines the materials used and the tests conducted to evaluate the properties of the materials used in the research. The methods section discusses details on the mix design, which specifies the proportions and properties of the materials used in the concrete mix. It shows how the different components of the concrete mix were prepared and proportioned. It also explains how the specimens were prepared and the specific tests conducted on them, including the details of the experimental setup and procedures.

The fourth chapter presents the results obtained from the research study. It includes a detailed analysis and interpretation of the data collected during the experimental phase. The chapter highlights the key findings, trends, and patterns observed in the data. The results are compared with the existing literature, and any significant observations or relationships are discussed. This chapter provides a thorough examination of the research findings to address the research objectives.

The final chapter summarizes the main findings of the study and draws conclusions based on the results and analysis. The chapter also discusses the implications of the findings, their significance in the context of the research area, and potential applications. Recommendations are also provided for future research directions or practical implementations based on the study's outcomes. This chapter provides closure to the thesis and offers a road map for future work in the field.

CHAPTER TWO

2 LITERATURE REVIEW

This chapter includes a theoretical literature review and an empirical literature review. In the first part theoretical reviews related concrete, plastic, and fly ash was discussed. The second part examine the empirical literature reviews based on experimental studies about fiber reinforced concrete, polypropylene plastic fibers and cement partial replacement with fly ash.

2.1 Concrete

Concrete is a composite material that consists essentially a binding medium within which are embedded particles or fragments of aggregates. In hydraulic cement concrete, the binder is formed from a mixture of hydraulic cement and water (ASTM C125, 2003). It is a versatile and widely used construction material known for its strength, durability, and affordability. This complex material composed of cement, aggregates (such as sand and gravel), water, and various additives materials. The combination of these components creates a tough material that can be shaped into different forms and used for a wide range of applications in the construction industry.

The primary binder in concrete is cement, a fine powder made from calcined limestone and clay. Cement acts as the glue that holds the other components together, providing the structural integrity and strength of the final concrete product. It undergoes a chemical reaction with water, known as hydration, which forms a hardened matrix that binds the aggregates. This process was first described by Powers and Brownyard (1948), who investigated the microstructure of cement paste and the development of its strength over time.

Cement hydration is a chemical reaction when water is added to cement, forming a solid matrix that binds the aggregates together and hardens over time. The hydration process involves complex chemical reactions between the cementitious compounds in cement and water molecules (Mindess et al., 2003).

According to Mehta and Monteiro (2013), during the cement hydration process, several chemical reactions take place. One of the primary reactions is the hydration of cement compounds, such as Tricalcium silicate (C3S), Dicalcium silicate (C2S), Tricalcium aluminate (C3A), and Tetracalcium aluminoferrite (C4AF). When water is added to cement, it reacts with these compounds to form calcium silicate hydrates (CSH) and calcium hydroxide (CH).The process begins when water molecules penetrate the surface of the cement particles and react with the compounds in the powder. This reaction releases calcium ions (Ca^{2+}) and hydroxide ions (OH^-) into the solution, initiating the nucleation and growth of the C-S-H gel. The C-S-H gel fills the voids between cement particles, providing cohesion and binding the aggregates.

Scrivener et al., (2015) also briefly discuss the different chemical reactions. As they explained, the hydration reaction of Tricalcium silicate (C3S) is the first and particularly significant in cement hydration. It is the major contributor to early strength development in concrete. As water reacts with C3S, calcium silicate hydrate (CSH) gel is formed; this provides initial strength and contributes to the hardening of concrete. Secondly Dicalcium silicate (C2S) undergoes hydration, but at a slower rate compared to C3S. It reacts with water to form additional calcium silicate hydrates (CSH) gel, contributing to the long-term strength and durability of concrete. Tricalcium aluminate (C3A) also reacts with the gypsum in the presence of water, leading to the formation of Ettringite and heat. This reaction generates heat and contributes to the early setting of concrete. Ettringite consists of long crystals that are only stable in a solution with gypsum. The compound does not contribute to the strength of the cement glue. Once all the gypsum is used up as per the previous reaction, the Ettringite becomes unstable and reacts with any remaining Tricalcium aluminate to form Monosulfate aluminate hydrate crystals.

Tricalcium Silicate (Alite) + Water→Calcium Silicate Hydrate+Lime+Heat ……… (Eq. 2.1)

$$2C_3S+6H \rightarrow C_3\underline{S}_2H_3+3CH,\ DH=120\ cal/g$$

Dicalcium Silicates (Belite)+ Water→Calcium Silicate Hydrate+Lime+Heat…….(Eq. 2.2)

$$C_2S+4H \rightarrow C_3\underline{S}_2H_3+CH,\ DH=62\ cal/g$$

Tricalcium Aluminate+Gypsum+Water → Ettringite+Heat……………………….…….(Eq. 2.3)

$$C_3A+3CSH_2+26H \rightarrow C_6 A \underline{S}_3 H_{32},\ DH=207\ cal/g$$

Tricalcium Aluminate+Ettringite+Water → Monosulfate Aluminate Hydrate…….. (Eq. 2.4)

$$2C_3 A+3\ C_6 A \underline{S}_3 H_{32}+22\ H \rightarrow 3\ C_4 A\ S\ H_{18}$$

The Monosulfate crystals are only stable in a sulfate deficient solution. In the presence of sulfates, the crystals resort back into ettringite, whose crystals are two-and-a-half times the size of the monosulfate. It is this increase in size that causes cracking when cement is subjected to sulfate attack. Tetracalcium aluminoferrite (C4AF) is another component of cement that undergoes hydration. It reacts with water to form calcium aluminoferrite hydrates (CAFH), contributing to the overall strength and durability of concrete.

During the early stages of hydration, a significant amount of heat is released, known as the heat of hydration. The heat of hydration of concrete refers to the heat released during the chemical reaction between cement and water, which leads to the formation of cementitious compounds and the hardening of concrete. This exothermic reaction plays a significant role in the early-stage development of concrete and can have implications for the design and construction of concrete structures. Various factors, including cement composition, water-cement ratio, curing conditions, and ambient temperature, influence the heat of hydration. The measurement and understanding of heat evolution are crucial for predicting and controlling the temperature rise in massive concrete structures to prevent thermal cracking and ensure the long-term durability of the concrete. Researchers have extensively studied the heat of hydration phenomenon, and several testing methods and models have been developed to quantify and predict the heat evolution in concrete. These include isothermal calorimetry, adiabatic calorimetry, and mathematical models based on the cement composition. The heat of hydration can also be influenced by using supplementary cementitious materials, such as fly ash or slag, which can reduce heat generation and mitigate potential thermal issues. Proper management of heat of hydration requires a balance between achieving sufficient early strength development and controlling the temperature rise to prevent cracking (Neville & Brooks, 2010; Mehta & Monteiro, 2013).

2.1.1 Cement: Types and Properties of cement

Cement is a vital component in the construction industry and is crucial in producing concrete, mortar, and other building materials. It is a finely powdered substance that, when mixed with water, forms a paste that hardens over time. Cement is primarily composed of clinker, a product obtained by heating limestone and other raw materials at high temperatures in a kiln. This clinker production involves a complex chemical process that results in the formation of compounds (Mindess et al., 2003). Cement provides the binding properties necessary to hold aggregates together, giving strength and durability to various structures.

Types of cement play a crucial role in construction, as they determine the properties and performance of concrete. A general overview of the two commonly used types of cement in construction, their composition, and specific applications is as follows:

Ordinary Portland Cement (OPC) : is the most widely used type of cement in construction. It is primarily composed of four significant minerals: Tricalcium silicate (C3S), Dicalcium silicate (C2S), Tricalcium aluminate (C3A), and Tetracalcium aluminoferrite (C4AF). Combining these minerals imparts OPC with its essential properties, including strength development, workability, and durability. The precise proportions of these minerals may vary, depending on the specific type of OPC being produced. One of the significant advantages of OPC is its early strength gain. OPC has high tricalcium silicate (C3S) content, contributing to concrete's early strength development. This characteristic makes OPC suitable for diverse construction projects where rapid strength gain is desirable, such as precast concrete elements or structures subjected to early loading. OPC is also known for its good workability, allowing it to be easily mixed, placed, and compacted. This workability is influenced by particle size distribution, chemical composition, and water-cement ratio. The balanced combination of these factors in OPC enables concrete production with desirable flowability, which is crucial for achieving proper consolidation and adequate placement in various construction applications (Kosmatka et al., 2002; Mehta & Monteiro, 2013).

Portland Pozzolana Cement (PPC): contains pozzolanic materials, such as fly ash, volcanic ash, or silica fumes. These materials react with calcium hydroxide during hydration, forming additional cementitious compounds. PPC offers improved workability, reduced heat of hydration, and enhanced durability. It is suitable for applications where enhanced workability and durability are desired, such as marine structures and hydraulic works (Neville, 2011).

PPC cement comprises approximately 10-25% pozzolanic materials, which are finely divided and react with the calcium hydroxide produced during cement hydration, forming additional cementitious compounds (ASTM C150/C150M , 2016). The addition of pozzolanic materials enhances the properties of PPC cement, making it more durable, resistant to chemical attacks, and capable of reducing the heat of hydration.

One of the significant advantages of PPC cement is its reduced environmental impact. Including pozzolanic materials in the cement mixture helps utilize industrial by-products such as fly ash, which would otherwise be disposed of as waste. In addition, this reduces the demand for traditional raw materials and minimizes greenhouse gas emissions associated with cement production (Maheshwari et al., 2019). The use of PPC cement offers several benefits to construction practices too. The reduced heat of hydration minimizes the risk of thermal cracking in large concrete structures and increases workability during hot weather conditions (Siddique, 2017). The improved durability and resistance to chemical attacks result in longer service life and reduced maintenance costs for concrete structures (Maheshwari et al., 2019). Furthermore, PPC cement contributes to resource conservation and promotes sustainable practices in the construction industry. It has an extensive application in various construction projects. It is commonly used to construct dams, bridges, foundations, and structures exposed to aggressive environments. The pozzolanic properties of PPC cement contribute to its ability to resist chemical attacks from sulfates, chlorides, and other harmful substances. Moreover, PPC cement exhibits excellent workability and produces a dense concrete matrix with reduced permeability, enhancing its durability in long-term service (Shetty, 2012).

Cement possesses various properties that contribute to its performance and durability in different structural elements. The chemical composition of cement consists of significant compounds, including Tricalcium silicate (C3S), Dicalcium silicate (C2S), Tricalcium aluminate (C3A), and Tetracalcium aluminoferrite (C4AF). These compounds undergo hydration reactions with water, forming hydration products that contribute to the strength and setting characteristics of cement (Mindess et al., 2003). The setting time of cement refers to the time it takes for the cement paste to harden and acquire sufficient strength, and it can be influenced by cement composition, fineness, and chemical admixtures. The setting time can be adjusted to meet specific construction requirements by incorporating additives or altering the composition of the cement (Mehta & Monteiro, 2013). Cement also plays a critical role in providing the necessary strength to concrete structures. The hydration process leads to the formation of calcium silicate hydrates (C-S-H) gel, which contributes to the strength development over time. The type and proportion of cement compounds, curing conditions, and water-to-cement ratio significantly affect the strength characteristics of cementitious materials (Neville & Brooks, 2010). Additionally, the fineness of cement, which refers to the particle size distribution and surface area, has an impact on its performance. Finer particles provide greater surface area for chemical reactions, resulting in improved strength and early-age properties of cement paste. The fineness of cement is commonly assessed using Blaine fineness or specific surface area measurement (Kosmatka et al., 2002).

2.1.2 Aggregate: Types and Properties of Aggregates

Aggregate for concrete refers to the inert granular materials, such as crushed stone, gravel, sand, or recycled materials, combined with cement and water to form a solid concrete matrix. Aggregates make up most of the volume in concrete and play a crucial role in providing strength, durability, and workability to the final product.

According to ACI 116R-10, aggregates are defined as “granular materials, such as sand, gravel, crushed stone or iron blast-furnace slag, used with a cementing medium to form a hydraulic-cement concrete or mortar”. These materials are sourced from natural deposits or manufactured through various processes, and their physical and chemical properties significantly impact the performance and characteristics of concrete.

Aggregates significantly influence the properties of concrete, including its strength, workability, and durability. A study by Brown and Smith (2022) demonstrates that the compressive strength of concrete increases with a higher aggregate content up to a specific limit. The particles interlocking mechanism within the matrix enhances load transfer, improving strength. However, excessive aggregates can lead to decreased workability and increased segregation (White, 2019). They also provide the primary load-bearing capacity of the hardened concrete. The interlocking arrangement of aggregates within the cement paste creates a solid composite material that can resist compressive forces. Additionally, aggregates contribute to the overall durability and resistance of concrete against factors such as abrasion, freeze-thaw cycles, and chemical attacks (Mindess et al., 2003).

Moreover, the shape and surface texture of aggregates directly impacts the workability of concrete. Spherical or rounded aggregates tend to improve the flowability of the mix, making it easier to handle during placement (Clark et al., 2020). Conversely, angular and rough-textured aggregates increase the frictional resistance, making the concrete mix stiffer but more stable regarding slump and segregation (Green et al., 2021).

Aggregates are materials commonly used in construction that are added to concrete, mortar, or asphalt mixes to provide strength, stability, and volume. There are several types of aggregates available, and they can be categorized based on their origin, size, and composition. Here are some common types of aggregates:

Natural Aggregates: These aggregates are obtained from natural sources such as crushed stone, gravel, sand, or river rock. ASTM C136 provides standard methods for determining the sieve analysis of fine and coarse aggregates, allowing for evaluating their gradation characteristics. They are commonly used in construction and can be further classified based on their size as fine aggregates and coarse aggregates. Fine aggregate, commonly known as sand, consists of particles ranging in size from 0.075 to 4.75 mm. It is typically sourced from natural deposits or manufactured from crushed rock. Fine aggregate plays a vital role in filling the voids between coarse particles and improving the workability and cohesion of concrete (Neville & Brooks, 2010). According to Smith (2018), the choice of fine aggregates significantly affects the workability and strength of concrete. Fine aggregates with a well-graded particle size distribution enhance the packing density and reduce voids, improving mechanical properties. Conversely, excessive fines can increase water demand and weaken the concrete matrix (Jones, 2020). On the other hand, coarse aggregate, comprises crushed stones, gravel, or recycled concrete with particle sizes between 4.75 mm and 75 mm. It provides strength and stability to concrete structures and is responsible for the bulk volume. Coarse aggregate can be further categorized into uncrushed or crushed gravel and crushed rock, each having its distinct characteristics (Mindess et al., 2015). In addition, coarse aggregates contribute to concrete's overall strength and stability. Research conducted by Johnson et al., (2019) suggests that using angular and rough-textured coarse aggregates improves the interlocking between particles, enhancing load-bearing capacity and reducing cracking potential. Furthermore, a larger aggregate size can result in a lower water-to-cement ratio, thus reducing shrinkage and improving durability (Thomas, 2021).

Recycled Aggregates: are derived from the processing of construction and demolition waste. They include crushed concrete, reclaimed asphalt pavement, and crushed bricks. Recycling these materials not only reduces the environmental impact of waste disposal but also provides a sustainable alternative to natural aggregates. Recycled aggregates can be used in various applications, including road bases and non-structural concrete (ACI 562.0R, 2016; Mehta & Monteiro, 2013).

Lightweight Aggregates: are materials with low density, typically derived from expanded clay, shale, or slate. These aggregates are used to produce lightweight concrete, which offers advantages such as improved thermal insulation and reduced dead load on structures. Lightweight concrete is commonly used in construction projects where weight reduction is desired, such as in high-rise buildings or precast elements (ACI 213R-14; Kosmatka et al., 2002)

Heavyweight Aggregates: are types of aggregate used in concrete that have a high density, typically exceeding 2080 kg/m^3. These aggregates are commonly employed in applications where there is a need for increased density and weight in concrete structures. Heavyweight aggregates can be natural or manufactured, and they offer several benefits and applications (ACI 304.3R-20; Neville & Brooks, 2010).

Understanding the types and properties of aggregates is also crucial for designing concrete mixtures that meet specific performance requirements. Which are:

Particle Shape: The shape of aggregate particles is an important property that significantly influences the performance of concrete. According to ACI 211.1.91 (2002), the shape of aggregate particles has a direct impact on the workability, strength, and durability of concrete. Angular and rough-textured particles tend to enhance the bond between the aggregate and the cement paste, leading to improved mechanical properties. The increased surface area of these particles promotes interlocking and provides more contact points for bonding within the concrete matrix. On the other hand, smooth and rounded particles may reduce interlocking and increase the workability of concrete. They offer lower resistance to flow, allowing for easier placement and compaction of the concrete mixture (Mehta & Monteiro, 2013).

Particle size distribution: is an important property that influences the workability and strength of concrete. Well-graded aggregates, which have a balanced distribution of particle sizes, result in a denser packing of particles and reduce voids in the concrete matrix, ultimately enhancing the strength of the concrete (Kosmatka et al., 2002). Proper particle size distribution is achieved through sieving and classification of the aggregate based on specific size ranges. The ASTM C136/C136M-19a standard provides guidelines for the sieving process and the determination of particle size distribution of fine and coarse aggregates. It specifies the equipment, procedures, and calculations involved in obtaining accurate and reliable particle size distribution data.

Surface Texture: Surface texture is an important property of aggregates that significantly influences the performance of concrete. The texture of aggregate surfaces plays a crucial role in the bond between the aggregate particles and the cement paste, ultimately impacting the overall strength and durability of concrete structures. It influences the bond between the aggregate and the cement paste. A rough surface texture provides more contact points for bonding, resulting in improved concrete interlocking and mechanical properties. Conversely, a smooth surface texture may reduce concrete's bond strength and overall performance (Neville & Brooks, 2010).

Moisture Content: The moisture content of aggregate affects the water-cement ratio and workability of concrete. Moisture in the aggregate contributes to the total water content in the concrete mixture, requiring adjustments in the mixing proportions to achieve the desired water-cement ratio (Mindess et al., 2003). Excess moisture can decrease strength and durability, while insufficient moisture can result in reduced workability. ACI 211.1-91 (2002) recommends that the moisture content of aggregates should be considered when determining the mixing water required for concrete. Excess moisture in the aggregates can increase the overall water-cement ratio, potentially leading to lower strength and reduced durability. On the other hand, insufficient moisture content may result in decreased workability of the concrete mixture. Proper adjustment of the mixing proportions based on the moisture content is necessary to maintain the desired water-cement ratio and ensure optimal performance of the concrete.

Specific Gravity: Specific gravity is the ratio of the density of a substance to the density of water. For aggregates, specific gravity is typically determined by weighing a sample of aggregate in air and then weighing the same sample in water (Mehta & Monteiro, 2013). It provides information about the volume and weight relationship, which influences concrete's workability and bulk density. ASTM C127/C127M-15 outlines the test method for determining coarse aggregates' specific gravity and absorption. Specific gravity is widely used in the construction industry to assess the quality and suitability of aggregates for concrete production. It helps in determining the optimal proportions of aggregates in the mix and evaluating the density and volume relationship of the concrete. Aggregates with a higher specific gravity generally contribute to higher concrete density, which can result in improved strength and durability.

2.1.3 Water

Water is a transparent, odorless, and tasteless liquid compound with two hydrogen atoms bonded to one oxygen atom (H_2O). It is the most abundant and essential substance on Earth, playing a critical role in various natural and human activities. Water exists in three primary states, solid (ice), liquid, and gas (water vapor), and undergoes constant cycling through evaporation, condensation, and precipitation. With its unique properties, such as high surface tension, excellent solvent capabilities, and thermal stability, water is a universal solvent, supports life, and plays a crucial role in numerous environmental, industrial, and biological processes (Hillel, 2012).

Likewise, water is a fundamental ingredient in the production of concrete. It is used to mix cement, aggregates, and other additives to form a workable and cohesive mixture. The water-cement ratio (w/c ratio) is a critical parameter determining the resulting concrete's strength and durability. Controlling the w/c ratio during concrete mixing is essential to achieve the desired properties and performance of the hardened concrete (ACI Committee 318, 2019). A higher w/c ratio generally increases workability, making the concrete easier to mix, place, and compact. However, a high w/c ratio can compromise the strength and durability of concrete due to increased porosity, higher shrinkage, and lower resistance to various forms of deterioration, such as freeze-thaw cycles and chemical attacks (Mehta & Monteiro, 2013).

Water content plays a critical role in the hydration process of cementitious materials in concrete. During hydration, water reacts with cement particles, initiating chemical reactions that form hydration products and contribute to concrete's hardening and strength development. Adequate water content is necessary for complete hydration, ensuring all cement particles are effectively activated. Insufficient water content can result in incomplete hydration and reduced strength, while excess water content can lead to increased porosity and decreased strength (Neville, 2011).

Curing helps prevent moisture loss from the concrete, allowing the hydration process to proceed effectively and ensuring the complete development of strength. The curing process, which involves maintaining adequate moisture in the concrete during the early stages of hydration, is also crucial for achieving optimal strength and durability. Proper curing practices, such as curing compounds, membrane curing, or moist curing methods, are essential to control water evaporation and provide a favourable environment for hydration (ACI Committee 308, 2015).

The movement and control of water in concrete are essential considerations for achieving durable and long-lasting structures. Concrete admixtures, such as water-reducing and Superplasticizers, can improve workability and reduce water content while maintaining the desired properties. Additionally, incorporating supplementary cementitious materials like fly ash or slag can enhance the durability and reduce the permeability of concrete, resulting in improved resistance to moisture ingress and chemical attacks (ACI Committee 232, 2002).

Water is also used in construction for site operations, such as dust suppression, equipment cooling, and soil compaction. Dust suppression is necessary for construction sites to minimize airborne particles that pose health risks to workers and nearby communities. Water is applied through sprayers or other methods to keep dust levels low and maintain a safe working environment. Additionally, water is used to cool equipment and machinery during construction activities to prevent overheating and ensure optimal performance (Bouzoubaa et al., 2007).

2.2 Properties of concrete

2.2.1 Fresh and hardened properties

Fresh properties of concrete refer to the characteristics exhibited by concrete in its plastic state, from the time of mixing to the early stages of hardening. These properties encompass various factors that influence freshly mixed concrete's workability, consistency, and behaviour. According to Mindess et al., (2003), fresh properties include workability, segregation resistance, bleeding, and setting time, collectively determining the ease of handling, placing, and finishing concrete.

Workability of concrete refers to its ability to be easily mixed, placed, compacted, and finished without excessive segregation, bleeding, or the need for excessive effort. It is a crucial property that impacts the ease and effectiveness of concrete construction processes.

According to ASTM C125,"Standard Terminology Relating to Concrete and Concrete Aggregates, "workability is" the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity. It further elaborates on the factors influencing workability, including water content, aggregate characteristics, mix proportions, use of admixtures, and any supplementary cementitious materials.

A workable concrete allows full compaction using a reasonable amount of work. This state helps to achieve the maximum possible density i.e., minimum possible voids of concrete, which results in more strength and durability (Neville & Brooks, 2010). The most critical factor influencing concrete's workability condition is its water content. Concrete will be easier to deal with as moisture content rises. But as the mix's water content increases, the mixture's strength will decline, leading to segregation and bleeding. The quantity of aggregate also influences the workability of concrete, the proportion of fine aggregate, and the geometry and texture of the aggregate particles. Concrete loses workability by increasing the aggregate amount while maintaining the water and cement content (Mikiyas, 1987).

ASTM C143, "Standard Test Method for Slump of Hydraulic-Cement Concrete," is commonly used to evaluate the workability of concrete. The test involves measuring the slump, which is the deformation or settlement of concrete when a cone-shaped mold is removed. The slump test indicates the concrete's consistency and ability to flow and be compacted. Generally, the standard classifies slump into True slump, shear slump, and collapse slump. First, in True Slump, the concrete subsides evenly without significant lateral movement. Slump values between 1 to 4 inches (25 to 100 mm) are typically appropriate for most applications. On the other hand, the concrete in shear slump type shears and loses cohesion, resulting in a collapsed appearance. This slump type is generally undesirable as it indicates excessive water content or lack of workability. The concrete shears and loses cohesion, resulting in a collapsed appearance. This slump type is generally undesirable as it indicates excessive water content or lack of workability. However, the concrete collapses entirely in a collapse slump and spreads outwards. This type of slump is typically not suitable for most construction applications.

Several key factors are affected by workability, including the ease of mixing, placing, and finishing concrete, as well as the uniform distribution of aggregates and reinforcement. Adequate workability ensures proper compaction, minimizing the presence of voids and ensuring the desired density and strength of the concrete. A concrete mix with optimal workability facilitates better cohesion between particles, resulting in improved homogeneity and reduced segregation. Workability significantly impacts the strength and durability of concrete. The water-cement ratio and workability are closely linked to the compressive strength of concrete, as proper workability allows for optimal hydration of cement particles, resulting in better bonding and higher strength development. Workability also influences the durability of concrete by affecting its resistance to factors such as freeze-thaw cycles, chemical attacks, and abrasion. Better workability leads to reduced porosity and improved resistance to detrimental effects. Various admixtures and supplementary materials can be incorporated into concrete to enhance workability. Superplasticizers, for instance, are commonly used to improve workability by reducing water demand while maintaining a consistent slump. Additionally, the inclusion of supplementary materials such as fly ash or silica fume can influence workability by altering the particle size distribution and chemical composition of the mix. It is essential for concrete practitioners and engineers to carefully consider and control the workability of concrete to achieve the desired performance and ensure the long-term durability of structures (Li et al., 2017; Kim & Lee, 2019; Ramezanianpour & Mahdikhani, 2019).

On the other hand, a hardened properties of concrete encompass a range of essential characteristics in assessing its performance and durability. These properties refer to the behavior and attributes of concrete after it has fully cured and hardened. Understanding and evaluating the hardened properties are crucial for ensuring concrete structures long-term integrity and functionality. Here are some of the hardened properties.

Compressive strength: is a fundamental mechanical property of concrete that measures its ability to withstand axial loads or forces. According to ASTM C39/C39M-20a, the compressive strength of concrete is determined by subjecting cylindrical or cubical specimens to a uni axial compressive load until failure occurs. The maximum load applied to the specimen is divided by its cross-sectional area to calculate the compressive strength. Compressive strength is a vital parameter in evaluating the structural integrity and load-bearing capacity of concrete elements. It depends on factors such as the water-cement ratio, aggregate properties, curing conditions, and cementitious materials used (Neville, 2010).

Splitting Tensile Strength: is a measure of a concrete specimen's ability to resist tensile forces applied perpendicular to its axial direction. According to ASTM C496/C496M-17, this test involves applying a diametrical compressive force to a cylindrical specimen until failure occurs along a diametrical plane. The maximum force at failure is divided by the cross-sectional area of the specimen to calculate the splitting tensile strength. This test provides valuable information on the tensile strength characteristics of concrete and is often used in design and quality control. It provides valuable information about the concrete's ability to resist cracking and withstand indirect tensile forces. The splitting tensile strength is influenced by various factors, including aggregate properties, water-cement ratio, curing conditions, and concrete mix design. This property is particularly relevant in structures where tensile stresses are dominant, such as slabs and walls, and helps in evaluating the overall structural integrity and durability (Kosmatka et al., 2002).

Flexural Strength: also known as modulus of rupture, measures the ability of concrete to withstand bending or tensile stresses. According to ACI 318-19, flexural strength is determined by subjecting a beam-shaped concrete specimen to a bending load until failure occurs. The maximum applied load is divided by the moment of inertia of the specimen to calculate the flexural strength. This test provides important information about the structural behavior and crack resistance of concrete elements subjected to bending or flexural forces. It indicates the concrete's capacity to withstand loads applied perpendicular to its longitudinal axis, typically encountered in beams, slabs, and other structural elements. The flexural strength of concrete is influenced by factors like the water-cement ratio, aggregate properties, curing methods, and reinforcement.

Durability: is a fundamental property of concrete that plays a crucial role in its long-term performance and service life. According to ACI 201.2R-16, durability is defined as the ability of concrete to resist weathering action, chemical attack, abrasion, and other potentially detrimental influences. It encompasses the resistance of concrete to degradation, such as cracking, spalling, corrosion of reinforcement, and loss of structural integrity, under environmental and operational conditions. Various factors influence it, including the quality of materials, mix design, construction practices, and environmental exposure conditions.

Durability and long service life are sometimes used interchangeably. It is typical to add a general reference to the environment when describing durability since durability under one set of conditions does not always imply durability under another. No material is naturally resistant to wear and tear; environmental interactions cause changes in the microstructure and, as a result, the characteristics of materials over time. Concrete's water absorption property is an essential property of concrete that influences its durability and performance. It refers to the ability of concrete to absorb water when exposed to moisture or submerged in water. It is influenced by various factors, including the porosity and permeability of the concrete matrix, the quality of materials used, curing conditions, and the presence of cracks or other defects (Neville & Brooks, 2010). When a material's qualities under certain usage conditions have deteriorated to the point that its further use is deemed harmful or unprofitable, it is presumed that the substance has reached the end of its useful life (Swaroop et al., 2013). When exposed to the environment, durable concrete will maintain its original shape, quality, and functionality. When subjected to various atmospheric conditions, the majority of waters and soils containing aggressive chemicals and many other types of chemical exposure, concrete will function properly. However, even the finest concrete will have a short usable life in some chemical situations unless special precautions are followed. Pressure applied to one side of concrete makes it more susceptible than otherwise because it pushes the aggressive solution into the concrete. The main areas of concern are exposure to sulfates, saltwater, salt from seawater, acids, and carbonation (ACI Committee 201, 2016).

One of the most aggressive environmental deteriorations that affects the long-term resilience of concrete buildings is sulfate attack. Many civil engineering constructions exposed to sulfate environments, such as piers, bridges, foundations, concrete pipes, etc., are affected by the sulfate attack on concrete, which causes expansion, cracking, and degradation (Al-Akhras, 2006). One of the primary causes of the expansion and degradation of concrete structures is sulfate attack. Sulfate ion interactions with various hydration products in the concrete structure are thought to be the cause of this expansion (Tang et al.,2015). Most soils contain some sulphate in the form of calcium, sodium, potassium, and magnesium. They occur in soil or ground water. Water used in concrete cooling towers can also be a potential source of sulphate attack on concrete. Therefore, sulphate attack is a common occurrence in natural or industrial situations. Solid sulfates do not attack the concrete severely but when the chemicals are in solution, they find entry into porous concrete and react with the hydrated cement products (Swaroop et al.,2013).

The most commonly occurring salts for sulfate resistance tests are sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$), as these salts most commonly occur in the water and soil that surround the concrete structure. These cation types (Na^+ or Mg^{2+}) related to sulfate ions define the mechanism of attack and significantly influence concrete deterioration (Skalny et al.,2002).

Sodium sulfate (Na_2SO_4) reacts with hydration products of cements, resulting in the formation of Ettringite (3CaO·Al2O3·3CaSO4·32H2O) and gypsum (CaSO4·2H2O). The provision of Ca^{2+} ions, necessary for Ettringite and gypsum formation, is supplied by portlandite (CH) or by decalcification of C-S-H gel. Decalcification of C-S-H gel affects the loss of bonding, and it is very dangerous. Gypsum is usually formed under mortar/concrete surface. In this region, aluminum ions are primarily consumed for the formation of ettringite and, therefore, sulfate ions can react only with the remained calcium ions and form gypsum (Chabrelie et al., 2011).

The interaction of ion species from $MgSO_4$ solution and hydration products of cements gives M-S-H gel and brucite (Mg (OH) 2) in addition to gypsum and ettringite, which are common reaction products in both solutions (Na2SO4, MgSO4). M-S-H gel does not have binding capacity. In the presence of brucite, decalcification of C-S-H gel is more prominent due to brucite low solubility (Mäkká et al.,2022). The saturated solution of brucite has a PH of 10.5, which is too low to maintain the stability of C-S-H, and the stability of calcium aluminate sulfate. The reaction of MgSO4 with calcium hydroxide is also followed by the formation of brucite layer on the specimen surface and gypsum under it (Skalny et al.,2002).

Nosouhian et al., (2015) have carried out research on the influence of magnesium sulfate concentration on durability of concrete. The results suggested that the 5% magnesium sulfate solution is the most deteriorating environment from the compressive strength reduction viewpoint, while the 14.7 % magnesium sulfate solution is observed as the most severe environment from expansion aspect.

The sulphate attack on cement concrete comprises two main categories internal and external sulphate attack (Nadir & Ahmed,2022). Internal sulphate attack was discovered in the middle of the 1980s, the damage caused by this attack is relatively "new" in comparison to the "conventional" external sulphate attack. Two different mechanisms of Delayed Ettringite Formation (DEF) caused by internal sulphate attack (Ali, 2013). There are three conditions mentioned by Alwash for the internal sulphate attack to take place. The first one is when preliminary micro cracks are needed where deposition of ettringite crystals can occur. Secondly, when it occurs in a sulphate-free environment for the late sulphate release from gypsum-contaminated aggregate, sulfur-rich clinker phase and high-sulphate cement. Lastly when it occurs in a moist environment favoring diffusion of SO3 and other ions (Ca++and Aluminate) through water-saturated capillary pores (Ali, 2013 and Alwash, 2005). On the other hand , External sulfate attack is the traditional sulphate attack, were chemical reaction of a sulphate is present in rich soil or ground water, with the cement paste determines the external sulphate attack generated damage, which is the traditional sulphate attack. Soils containing sodium, potassium, magnesium and calcium sulfates are the main sources of sulphate ions in ground water. Therefore, the following three conditions must be fulfilled: High permeability of concrete, Sulphate-rich environment and Presence of water (Ali, 2013).

2.2 Fiber reinforced concrete

Many years back the concept of using various continuous fibers were used in different materials which have increased the mechanical properties of materials to a large extent, but using small discrete discontinuous fibre addition to concrete starts recently. The various fibres that have been added to concrete until now are steel fibres, glass fibres, carbon fibres and synthetic fibres (Bhat et al., 2017). Fiber-reinforced concrete (FRC) is a composite material made of hydraulic cements, water, fine and coarse aggregate, and a dispersion of discontinuous fibers. According to ACI 544.3R (2008), fiber length varies from 0.25 to 2.5 in. (6 to 64 mm). FRC may also contain supplementary cementitious materials and admixtures commonly used with conventional concrete.

Hence concrete is brittle in nature when load acts on the concrete, the concrete deflects and small cracks start to grow from this point, although the load leading to failure not reached yet. But as the load is increased the cracks start to propagate which leads the concrete to collapses. However due to addition of fibers in concrete, it will control the cracks and their propagation but it should be in mind the modulus of elasticity of fibres should be larger than the concrete so that they can carry the load and also it will increase the tensile strength of the concrete. The main property of concrete which should be enhanced to a greater extent is the toughness since due to fibre pull out and de-bonding; fibres can increase the toughness to a greater extent and also it is showing an improvement in properties like impact resistance and fracture in loading (Xu, 2003).

Fiber reinforced concrete (FRC) contains discontinuous discrete fiber reinforcement, and it may also contain admixtures in commonly used conventional concrete. In general terms, a fibre is a or artificial substance that is significantly longer than its width. Natural fibers include those produced by plants, animals, and geological processes, which usually occur or evolve in fiber shape. In contrast, Man-made or synthetic fibers are fibers whose chemical composition, structure, and properties are significantly modified during the manufacturing process (Sukumar and John, 2014).

2.2.1 Plastic-made fibers

Plastic fibers, also known as synthetic fibers, are a type of reinforcement commonly used in concrete to enhance its mechanical properties. These fibers are made from various polymers, such as polypropylene (PP), polyethylene (PE), or nylon, and they come in different shapes and sizes. Plastic fibers are typically added to the concrete mix in small quantities to improve its tensile strength, toughness, and resistance to cracking. One of the key advantages of using plastic fibers in concrete is their ability to control cracking. The fibers act as a secondary reinforcement, dispersing throughout the concrete matrix and creating a three-dimensional network. This network helps to distribute stress and inhibit crack propagation, leading to improved crack resistance and durability of the concrete (ACI Committee 544, 2015).

Moreover, plastic fibers can enhance the impact resistance and ductility of concrete. The fibers absorb and distribute energy when subjected to external forces, improving the concrete's ability to withstand impacts and dynamic loads. This property is particularly beneficial in applications where the concrete is exposed to heavy traffic or potential impact events. The use of plastic fibers can also mitigate shrinkage and temperature-related cracking in concrete. By reducing the formation of shrinkage cracks, the fibers improve the overall appearance and long-term performance of the concrete. Additionally, plastic fibers can help control the development of early-age thermal cracking caused by temperature differentials (Li et al., 2019; Ceylan et al., 2016).

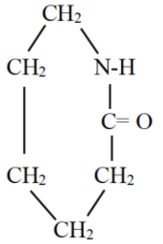
Plastics are materials made of significant organic (carbon-containing) molecules and may be shaped into a wide range of goods. The molecules composing plastics are long carbon chains that give plastics many valuable properties. Materials made up of long, chain-like molecules are called polymers. The word plastic is derived from the words plasticus (Latin for "capable of molding") and plastikos (Greek "to mold" or "fit for molding"). Plastics can be made hard as stone, strong as steel, transparent as glass, light as wood, and elastic as rubber. Plastics are also lightweight, waterproof, chemical resistant, and produced in almost any colour (Eltayef, 2003).

Parkesine, the first synthetic plastic, was created from cellulose in the middle of the 19th century and used in applications such as clothing, water proofer, and synthetic ivory. Almost half a century later, Bakelite became the first truly synthetic plastic developed. However, it was not until 1950 that global plastics production began its unprecedented growth, which has seen it expand 230-fold to the present day. Due to their distinctive qualities, including their high strength-to-weight ratio, great moldability, impermeability to liquids, resistance to physical and chemical degradation, and low cost, plastics have experienced tremendous progress. In various applications, they can easily substitute for other materials, such as glass, metal, wood, and natural fibers. However, some of the desirable qualities of plastics are also their fundamental limitations. Due to their remarkable resistance to physical and chemical deterioration, plastics can linger for decades or centuries as environmental waste (OECD, 2022).

According to Frank and Biederbick (1984), the basic structure of plastics (or polymers) is given by macro-molecule chains formulated from monomer units by chemical reactions. Typical reactions for chain assembling are Poly-addition as chain reaction, Poly-addition as stepwise reaction and Poly-condensation. Poly-addition as chain reaction is a chemical combination of many monomer molecules, in which the monomers will be combined to a chain either by orientation of the double bond or by ring splitting. No byproducts will be separated, and no hydrogen atoms will be moved within the chain during the reaction. The process will be started by energy consumption (by light, heat or radiation) or by use of catalysts. The process of Poly-addition as stepwise reaction combines monomer units without a reaction of double bonds or separation of low molecular compounds. Hydrogen atoms can change position during the process. However, in Poly- condensation chain assembling reaction, generation of plastics by buildup of poly functional compounds. Typical small molecules like water or ammonia can be set free during the reaction. The reaction can occur as a step reaction.

The monomer units are carbon-based organic molecules. Besides carbon and hydrogen atoms as main components, elements like oxygen, nitrogen, sulfur, fluorine, or chlorine can be contained in the monomer unit. The element type, proportion, and placement in the monomer molecule give the basis for generating different plastics, as shown in Table 2.1.

Table 2.1 Examples of some common plastics and their monomers. (Klein, 2011)

Monomer		Polymer	
Ethylene	$CH_2=CH_2$	Polyethylene (PE)	$[CH_2-CH_2]_n-$
Propylene	$CH=CH_2$ | CH_3	Polypropylene (PP)	$-[CH-CH_2]_n-$ | CH_3
Vinylchloride	H / CH_2-C \\ Cl	Polyvinychloride (PVC)	$-[CH-CH_2]_n-$ | Cl
Caprolactame		Poly(E-caprolactame) (PA6)	O ‖ $-[NH-(CH_2)_5-C]_n-$
Tetraflourethylene $CF_2=CF_2$	Polytetraflourethylene (PTFE)	$-[CF_2-CF_2]-$	$-[CF_2-CF_2]_n-$

Plastics are categorized broadly into four main groups: Thermoplastics, Elastomers, Thermosets, and Polymer compounds. The class of every plastic material is determined by its macromolecular structure and physical characteristics. Thermosets and Elastomers have hard and soft elasticity, but their resins cannot be melted for recycling. However, thermoplastics are either amorphous or semi-crystalline. Amorphous resins are disordered, statistically oriented macromolecules, whereas semi-crystalline resin macro molecules are nearly ordered since they are embedded with crystalline phases. Typical semi-crystalline resins include polyamide and polypropylene, whereas standard amorphous resins mainly include polycarbonate, polystyrene, and polyvinyl chloride (Maddah, 2016).

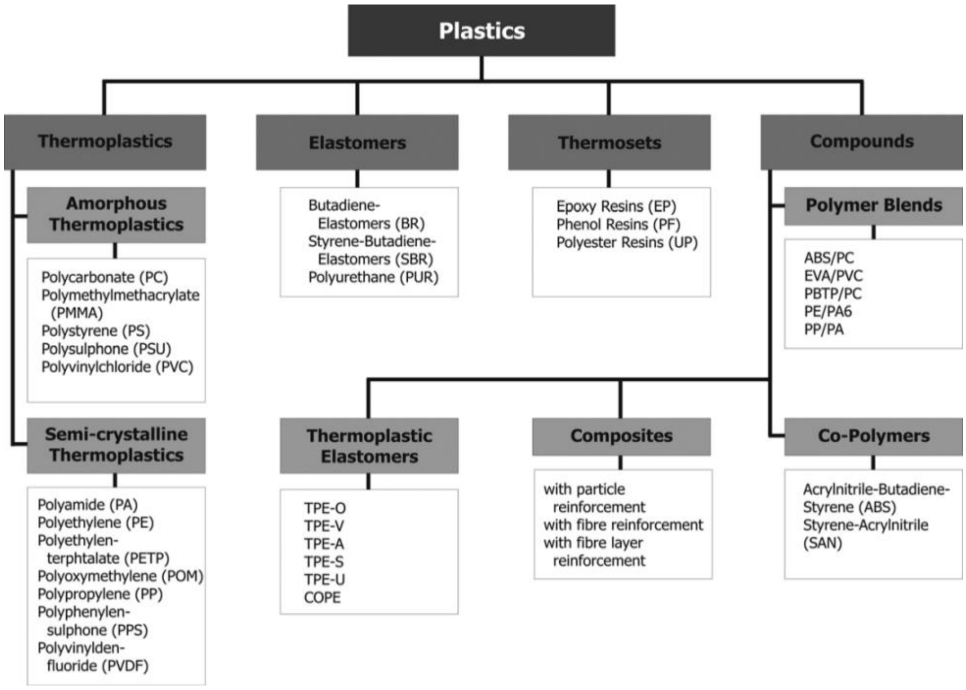


Figure 2.1 Classification of plastics (Klein, 2011)

Thermoplastics are materials that exhibit unique properties such as high strength, durability, and flexibility. They are used in various industries, including automotive, construction, packaging, and medical. These plastics can be melted and reshaped multiple times, making them highly versatile and cost-effective materials (William & Rethwisch, 2013).

Thermoplastic plastics have several properties that make them highly desirable in various industries. Its high strength-to-weight ratio makes it lightweight yet robust (Suresh & Chandramohan, 2017). They are also highly flexible and can be molded into complex shapes, making them ideal for various applications. Additionally, thermoplastics have excellent chemical resistance, making them suitable for use in harsh environments such as the chemical industry (Biron & Mollet, 2011).

Due to their unique properties, the application of thermoplastics is a wide range. They offer advantages over traditional materials, including ease of installation, reduced maintenance requirements, and improved cost-effectiveness (Khan & Sheikh, 2014). The construction industry uses thermoplastics due to their low cost, high strength, durability, and excellent weather ability (Middleton & Tipto, 2000). The automotive industry also uses thermo-plastics to produce lightweight components such as bumpers, dashboards, and interior trims (Biron & Mollet, 2011). Also, thermoplastics are used in the medical industry to produce disposable medical devices such as syringes, catheters, and IV tubing (Wicks & Pappas, 2007).

There are several types of thermoplastic plastics, each with unique properties and applications. Polyethylene (PE), Polyvinylchloride (PVC), Polypropylene (PP), Polystyrene (PS), and Acrylonitrile-butadiene-styrene (ABS) are the common thermoplastics used, each with their specific properties and applications (Pletcher & Walsh, 2013).

2.2.2 Polypropylene plastic and fiber

Polypropylene plastic, often called PP, is a versatile semi-crystalline thermoplastics polymer belonging to the polyolefin family. It is a widely used material due to its excellent properties, including high strength, chemical resistance, and thermal stability. Polypropylene is produced by polymerizing propylene monomers, resulting in a linear macromolecular structure. The resulting polymer has a high degree of crystallinity, contributing to its mechanical strength and stiffness (Brydson, 2017).

Giulio Natta discovered polypropylene plastic in 1954, and because of its low density as compared to other conventional polymers, it quickly gained popularity. Propylene is one of the most important industrial chemical products obtained from petroleum to produce various chemical derivatives. The dominant outlet for propylene is PP which accounts for nearly two-thirds of global propylene consumption (Maddah, 2016).

PP exhibits a relatively low density, making it a lightweight material. It has a density range of 0.895 to 0.92 g/cm^3, significantly lower than other plastics such as polyethylene and polyvinylchloride (PVC). The low density of polypropylene makes it suitable for applications where weight reduction is desired, such as automotive components, packaging materials, and consumer products (Mallikarjunan et al., 2020). In addition to its chemical resistance, polypropylene also exhibits good thermal stability. It has a high melting point, typically 130 to 171°C, depending on the specific grade and additives used (Brydson, 2017). This thermal stability allows polypropylene to withstand elevated temperatures without significant degradation, making it suitable for high-temperature applications or processes.

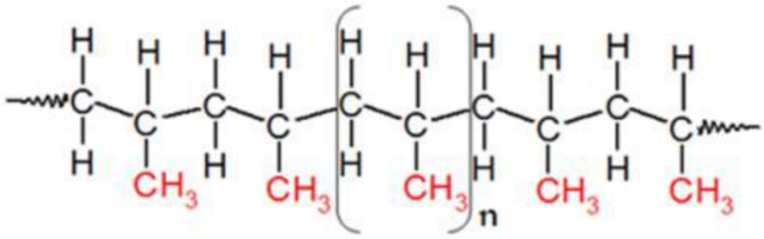


Figure 2.2 Polypropylene structure (Maddah, 2016)

Propylene is produced primarily from naphtha steam cracking, gasoline refinement, and propane de-hydrogenation. It is also an essential material among polyolefin's due to three main reasons. First, PP is ideal for long-life applications because of its excellent physical and chemical inertness features and inexpensive cost. Second, it is a highly versatile material, making it possible to create various structural designs and mechanical qualities. Third, PP may take on a variety of morphological structures by combining them with other polymers and adding fillers or reinforcement, which results in unique properties. Elastomer-modified PP, elastomer-modified filled PP, glass fiber-reinforced PP, filled PP, esthetic-filled PP, flame- retardant PP, and thermoplastic elastomers are examples of exceptional and reinforced polypropylene grades (Galli et al., 1984).

Polypropylene has a high stiffness, crystalline structure, and melting temperature than other commercial thermoplastics. The methyl groups in its molecular chain structure caused the substance to be hard. PP is also relatively rigid, low-density, and somewhat resistant to impacts. Also ,its chemical resistance can be described as enduring diluting or concentrated acids, alcohols, bases, aldehydes ,esters, aliphatic hydrocarbons, ketones, and limited resistance to aromatic and halogenated hydrocarbons and oxidizing agents. The typical crystallinity of PP is between 40-60%. In addition, PP is a low-cost thermoplastic polymer with superior properties like flame resistance, transparency, high heat distortion temperature, dimensional stability, and recyclability, making it ideal for a wide range of applications (Quazi et al.,2013).

Polypropylene (PP) plastic has extensive applications in the construction industry due to its unique combination of properties, including high chemical resistance, lightweight nature, and excellent durability. It is used in various construction applications, such as in fiber reinforcement, piping systems, roofing membranes, geotextiles, and insulation materials, contributing to the advancement of the construction sector (Dew, 2012).

Fiber-reinforced polypropylene composites FRPCs are perfect for applications related to construction, sports equipment, and automobiles because of their improved durability, moisture resistance, and high-strength characteristics. Unlike natural fibers, synthetic fibers exhibit better mechanical qualities. Glass fibers are frequently used as a synthetic reinforcement with PP to create composites with excellent mechanical characteristics. However, various fiber treatments and coupling agents regulate the mechanical properties of composites. Another important consideration in the design of composite materials is fiber diameter and aspect ratio. A particular value of fiber diameter thickness should not be exceeded; if so, fibers will decrease composite strength (Quazi et al., 2013).

The aspect ratio is an important parameter that influences the effectiveness of fiber reinforcement in concrete. The aspect ratio of polypropylene fiber refers to the ratio of its length to its diameter. Polypropylene fibers commonly used in concrete reinforcement typically have aspect ratios ranging from 50:1 to 150:1. Higher aspect ratios indicate longer and thinner fibers, which can enhance the concrete matrix's mechanical properties and crack resistance. However, it is essential to note that the optimal aspect ratio may vary depending on the specific application and desired performance requirements (Li et al., 2019).

Due to its low tensile strength and flexibility, conventional concrete is brittle and prone to fracture. Some concrete's flaws in construction include a less tensile capacity, poor bending resistance, and inadequate fracture resistance. Concrete's interior is readily penetrated by water or other damaging ions, which rush the concrete's degeneration (Hussain et al., 2020). The ease with which micro cracks may be formed from the outside to the inside causes the concrete to become more porous. When introducing polypropylene fiber, the concrete composite may generate a three-dimensional random distribution network structure, preventing micro-cracks formation (Qin et al., 2019).

Table 2.2 Physical characteristics of PP fibers (Gao et al.,2023; Eidan et al,2019; Yin et al.,2019)

Type of Fiber	**Tensile Strength (MPa)**	**Specific Gravity (gr/cm3)**
Recycled PP fiber	300-400	0.9-0.92

2.3 Fly ash as a supplementary cementitious material

Many high energy powered industries depend heavily on coal combustion products (CCPs). The combustion of pulverized coal in the furnace of a power station boiler results in the production of a number of solid products traditionally regarded as wastes but more accurately classified as coal combustion products. CCPs are the byproducts generated from burning coal in coal-fired power plants. These byproducts include fly ash, bottom ash, boiler slag, fluidized-bed combustion ash, or flue gas desulfurization. Coal ash is used interchangeably for different ash types (Tharaniyil, 2004).

According to the World coal ash association 2018 report, the worldwide production of coal combustion products was approximately 780 million metric tons (Mt). The largest coal combustion product producing countries and reigns were China 395 Mt, North America 118 Mt, India 105 Mt, European Union (EU15) 52.6 Mt, Africa 31.1 Mt, and the Middle East as minor contributors. In Africa, 92% of production coal combustion products were produced in South Africa. From 780 Mt of the global CCPs produced, some 415 Mt or 53 % were reported as utilized. Utilization rate varies widely from country to country depending on the quality of CCPs produced, technological capability, and degree of awareness of utilization possibilities.

Ethiopia, a country in East Africa, has been experiencing rapid economic growth and industrialization in recent years, leading to an increased demand for energy. While Ethiopia primarily relies on renewable energy sources such as hydro and wind power, coal has emerged as an additional energy resource for different factories. The Ethiopian government has also initiated coal-fired power plant projects, such as the Genale Dawa III project, to meet the rising energy demands (Wazir,2021). Consequently, the production of CCPs as a by- product of coal combustion has become a relevant topic.

Coal combustion products CCPs, includes fly ash, bottom ash, and flue gas desulfurization (FGD) gypsum. Fly ash, a fine powdery material is collected from the flue gases of coal-fired power plants, while bottom ash accumulates at the bottom of the furnace (Jiru et al., 2020). FGD gypsum is produced through the flue gas desulfurization process, which removes sulfur dioxide from the flue gases (Ahmed et al., 2018). These CCPs have potential applications in multiple sectors, from construction to agriculture.

One significant application of CCPs is in the construction industry. Due to its pozzolanic properties, fly ash can be used as a partial replacement for cement in concrete production. This reduces the demand for cement and enhances the durability and strength of concrete structures (Jiru et al., 2020). Researchers have studied using fly ash as a cementitious material in concrete, showcasing its potential to enhance sustainable construction practices (Tesfaye et al., 2022).

2.3.1 Fly Ash

Fly ash is “a finely divided residue that results from pulverized coal combustion and is transported by flue gases" (ASTM C618, 2017). It consists mainly of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and calcium oxide (CaO), along with other minor constituents. Fly ash is typically collected from power plant exhaust gases using electrostatic precipitators or other emission control devices. It is comprised of the non-combustible mineral portion of coal. When coal is consumed in the power plant, it is first ground to the fineness of the powder. Blown into the power plants boiler, the carbon is consumed, leaving molten particles rich in silica-alumina and calcium. These particles solidify as microscopic, glassy spheres collected from the power plant's exhaust before they can fly away-hence the product's name, fly ash (Patil, 2017).

Fly ash exhibits pozzolanic properties, which means it reacts chemically with calcium hydroxide (lime) in the presence of water to form additional cementitious compounds. This reaction, known as the pozzolanic reaction, leads to the formation of calcium silicate hydrates (C-S-H) gel, like the hydration process of cement. The chemical composition of fly ash varies depending on the type of coal, combustion conditions, and collection methods. It typically consists of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO), and other minor constituents. The proportions of these components affect the reactivity and pozzolanic properties of fly ash, contributing to the improved strength, durability, and workability of concrete mixtures (Mehta & Monteiro, 2013).

FA is extensively used as a supplementary cementitious material in concrete production. It can partially replace cement in concrete mixtures, reducing the environmental impact and improving specific properties of concrete. Incorporating fly ash in concrete can enhance workability, reduce the heat of hydration, increase long-term strength, improve resistance to sulfate attack, and reduce the permeability of concrete (ACI Committee 232,2002).

Fly ash is broken down into primary, secondary, and tertiary phases based on the formation time. There is no change in the preliminary stages. Secondary stages, including oxides and silicates, are created during coal burning. In addition, the movement of FA containing portlandite (hydroxide-bearing mineral typically included in the oxide mineral class) and gypsum produces the tertiary phases. The main components of FA are trace elements, silicon, oxygen,calcium,aluminum,carbon,iron,magnesium,potassium,hydrogen,titanium,sodium,phosphorus,nitrogen,and barium. The FA particle cooling rate impacts the production of inorganic materials. Slow cooling produces big crystalline particles, and rapid cooling has small glassy particles. Most FA's composition comprises inorganic materials combined between crystalline and amorphous phases. It accounts for 5 to 50%of its mass in crystalline FA phases. These phases are recognized using XRD to differentiate between the reactive and stable phases (Alterary & Marei, 2021).

According to ASTM C618 (2017), There are two basic types of fly ash: Class F and Class C. Fly ash belong to Class F if the sum of SiO_2+Al_2O_3+Fe_2O_3 is greater than 70% and belongs to Class C if the sum of the constituents SiO_2+Al_2O_3+Fe_2O_3 greater than 50% but may be significantly less than the 70 percent of Class F minimum limit. Both these fly ashes undergo a pozzolanic reaction with lime (Calcium hydroxide) created by the hydration of cement and water to form calcium silicate hydrate-like cement. In addition, some Class C fly ashes may possess enough lime to be self-cementing in addition to the pozzolanic reaction with lime from cement hydration.

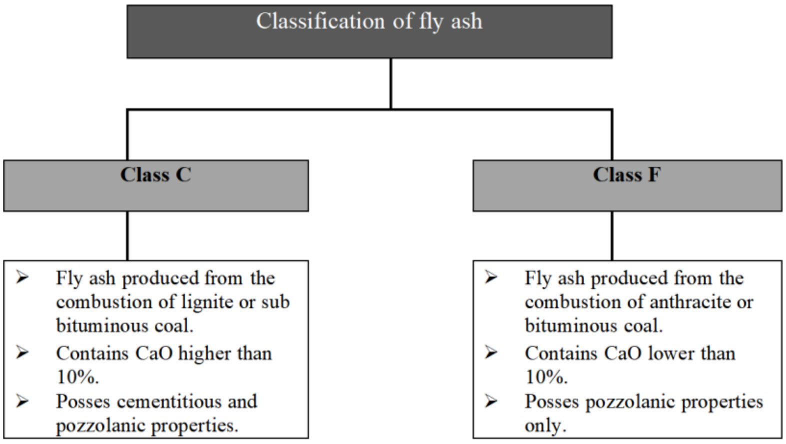


Figure 2.3 Classification of fly ash according to ASTM C618 (2017) illustrating the main differences

2.3.2 Properties of fly-ash

The fly ash or pulverized fuel, which is the residue, is collected by the mechanical dust collector or electrostatic precipitators from the fuel gases of thermal power plants. The composition of fly ash varies with the fuel burnt, the load on the boiler, and the type of separator. Like Portland cement, fly ash contains oxides of calcium, aluminum, and silicon, but the amount of calcium oxide is considerably less. The carbon content should be as low as possible, whereas the silica content should be as high as possible. Fly ash obtained from an electrostatic precipitator (ESP) may have a specific surface of about 350 to 500 m^2/kg.i.e., finer than portland cement (Patil, 2017).

Fly ash, which is a fine particulate material collected from the flue gases of coal-fired power plants, is predominantly composed of spherical glassy particles rich in silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). The particle size distribution of fly ash can vary depending on combustion conditions and coal composition. Fly ash's physical and chemical properties play a crucial role in determining its suitability for specific applications (Chindaprasirt et al.,2018).

The chemical composition of fly ash is a crucial determinant of its behavior and potential applications. High silica content in fly ash enhances its reactivity and contributes to the pozzolanic properties (Chindaprasirt et al., 2018). The alumina and iron oxide content also influence the hydraulic activity of fly ash, affecting its suitability for specific applications (Fernández-Jiménez et al., 2005). Different types of fly ash, such as Class F (low-calcium) and Class C (high-calcium), have distinct chemical compositions and exhibit varying properties.

The fineness of fly ash particles also significantly impacts their reactivity and workability in various applications. Finer particles tend to exhibit higher pozzolanic activity and contribute to improved concrete performance (Manso et al., 2016). The specific surface area of fly ash, determined by particle size distribution, influences its water demand, setting time, and overall strength development (Shi et al.,2017).

One critical property of fly ash is its pozzolanic activity, which refers to its ability to react with calcium hydroxide in the presence of water to form cementitious compounds. The pozzolanic activity of fly ash is influenced by chemical composition, fineness, and mineralogy (Malhotra, 1994). Pozzolanic fly ash can improve concrete's long-term strength and durability when used as a partial replacement for cement. Through the pozzolanic activity, fly ash combines with free lime to produce the same cementitious compounds formed by the hydration of Portland cement. Early in the curing process, the rate of strength gained for fly ash concrete is noticeably slower because of this set of chemical reactions (Patil, 2017).

The ability of fly ash to reduce environmental problems is another distinctive quality of the material. As a byproduct of coal combustion, fly ash contains trace elements, including heavy metals. Proper management and utilization of fly ash are crucial to prevent potential environmental contamination. Various studies have explored techniques to reduce the leachability of heavy metals from fly ash, ensuring its safe utilization (Gao et al., 2020). Furthermore, incorporating fly ash in construction materials reduces the demand for cement, decreasing carbon dioxide emissions and overall environmental impact.

2.4 Empirical literature review

2.4.1 Concrete with fiber reinforcement

The following experimental literature reviews show some of the findings regarding fiber-reinforced concrete investigation.

Muslim & Khudhair (2016) found in their research that steel fiber has a very substantial impact on concrete because it increases the strength of concrete by preventing the spread of micro-cracks caused by loading on concrete members like beams and slabs. The mix proportion was 1:2:4 (cement: sand: gravel) by volume for all mixes. Steel fiber made up a certain percentage of the concrete volume in the investigation. Using 0 % as the control mix, 0.1%, 0.2 %, 0.5 %, and 1.0 % of steel fibers, these ratios increased the compressive, tensile, and flexural strength of concrete, with the improvement in flexural strength being particularly notable.

Saluja et al., (1992) conducted experimental research using straight steel fibers with aspect ratios of 75, 90, and 105 to examine the compressive strength of concrete. They concluded that steel fibers could raise compressive strength to a maximum of 13.5 % at a 1.50 percent fiber concentration. Additionally, an equation was created to forecast the outcomes of the experiment.

Paul et al. (2020), In their article reviews, the performance of fiber-reinforced concrete (FRC) with the resilience of concrete infrastructures. FRC's tensile strength and ductility can be increased by adequately incorporating steel or non-metallic fibers. The improved tensile properties of FRC, which are used to build infrastructure, are shown in this review to significantly increase longevity, mainly through fiber bridging and fracture control. The data is supported by published laboratory tests conducted under regulated conditions and the observed functionality of existing FRC built infrastructure.

Fadhil and Yaseen (2015) have discussed in their article the effects of adding waste plastic fiber (PET) that results from manually cutting the plastic beverage bottles to the precast concrete panels. The study offers an experimental plan for examining the impact resistance and rupture strength of precast concrete panels with various depths. Different volumes of fibers, i.e., 0%, 0.5%, 1.0%, and 1.5%, have been added as percentages of concrete by volume. The results show that the maximum volume of PET fiber for a desired rupture and impact resistance was 1.0 %. Adding waste PET fiber to the plain precast concrete panels has economic advantages. It tends to decrease the depth panel from (30 cm× 30 cm×4 cm) to (30 cm×30 cm×3 cm) and the percentage of increase of rupture strength was 34.27 %, and the rate of growth of impact resistance was 157.14 % for reinforced concrete panels (30 cm×30 cm×3 cm) aged at 90-days compared with plain panels of (30 cm× 30 cm×4 cm). The fiber-reinforced precast concrete panel (FRPCP) specimens in the impact test were seen to have stayed intact despite being fractured, in contrast to the complete disintegration of the plain concrete sample.

Małek et al. (2020), in their inquiry into environmental reasons, polypropylene fibers derived from recycled plastic packaging were employed. After 1, 7, 14, and 28 days, the compressive, flexural, and split tensile strengths were evaluated. Additionally, the initial and final binding timings were established. This experiment used two types of recycled polypropylene fibers, a green polypropylene fiber (PPG) and a white polypropylene fiber (PPW), with three different cement contents (0.5, 1.0, and 1.5 wt %). The first green polypropylene fiber (PPG) is made from the cutting process of waste material (approximately 1 micron diameter and 30.9±0.5 mm length), while the second fiber, white polypropylene fiber (PPW) was modified into the extruder (about 1 micron diameter and 31.2 ± 0.5 mm length) to increase its adhesion to the cementitious mix. The addition of fibers enhanced the characteristics of concrete. The concrete with 1.0% polypropylene fibers for each type of fiber had the highest mechanical property values. For polypropylene fiber-reinforced concrete, the result of an increase in mechanical qualities when recycled fibers are added over unreinforced concrete is astonishing and exceptional (69.7% and 39.4% increase in compressive strength for green polypropylene fiber (PPG) and white polypropylene fiber (PPW) respectively, 276.0 % and 162.4 % increase in flexural strength for PPG and PPW respectively, and 269.4 % and 254.2 % increase in split tensile strength for PPG and PPW respectively.

Mahmood and Kockal (2022), their research focus on the characteristics of mortars reinforced with waste PVC fiber that contains silica fume and micro silica. The mortar mixtures had volume fractions of 0 %, 1 %, 2 %, and 3% plastic fibers. By weight of cement, silica fume and micro silica were substituted for 5 %, 10 %, and 15 % of the cement, respectively. There were 28 different types of mortar groupings produced in total. The results demonstrated that using waste PVC plastic fibers improved mortars' elasticity and deformation behavior. It has been shown that fibers prevent crack spread and preserve integrity while increasing the ductility of the mortars. However, the mortar samples' physical and mechanical characteristics decreased due to the fiber addition.

Rao et al.,(2019) studies on concrete were conducted to examine various properties of the HDPE polymer-reinforced concrete with varied fiber contents, including testing for workability, compressive strength, beam flexure, and plastic shrinkage tests (i.e., 0.67% and 0.45 % of the volume of concretes in the M40 and C25 grades, respectively) by two different fiber aspect ratios (75 and 125) and compared with the properties of standard concrete to evaluate the effect of the aspect ratios in HDPE Reinforced Concrete. Compared to plain concrete, the mechanical and plastic shrinkage properties of M40 and C25 grade HDPE Fibre Reinforced Concrete were significantly improved by the fiber aspect ratio. The minor aspect ratio of FRC (i.e., 30 mm length of HDPE fibers) showed better performance than the higher aspect ratio of FRC (i.e.,50 mm length HDPE fiber). Since the strength of concrete is inversely proportionate to its workability, adding HDPE fibers to the concrete mixture rendered it less workable. When the water-to-cement ratio is raised, the fresh density of concrete decreases, and when the aspect ratio, or HDPE fiber length, is raised, the fresh density substantially increases.For the volume fractions of the M40 and C25 classes, which are 0.45 % and 0.67 %, it was discovered that the flexural strength and compressive strength qualities of concrete with 75 aspect ratio (30mm length) HDPE FRC were greater, followed by that of 125 aspect ratio (50mm length) HDPE FRC. It was observed that increasing the fiber volume fraction and aspect ratios resulted in a decrease in the average shrinkage cracking length and the number of cracks that formed on the thin slab's surface. As these values are obtained only by eye judgment, better results can be expected by assessing the cracks with the help of an optical microscope.

Ahmad et al., (2022), in their study, collected information from already carried out research on polypropylene fibers. Essential characteristics of concrete, such as workability, compressive, tensile, and flexural strength, were reviewed. The review also explored cracking behavior and failure modes of polypropylene fiber-reinforced concrete. Furthermore, durability aspects, such as water absorption, porosity, dry shrinkage, and microstructure study (scan electronic microscopy), were also reviewed. Results indicate that polypropylene fiber improved the mechanical strength and durability of concrete (particularly tensile capacity) but decreased the flowability of concrete. The optimum dose was substantial, as a higher amount adversely affects strength and durability due to a lack of flowability. Scanning electronic microscopy results indicate that the polypropylene fibers restrict the propagation of cracks, improving concrete strength and durability. The review also implies that shrinkage cracks are considerably reduced with the addition of polypropylene fibers. Finally, the study also provides future research guidelines for upcoming generations to improve the performance of polypropylene fibers that reinforce concrete by adding different secondary cementitious materials, such as fly ash or silica fume, into polypropylene fiber reinforced concrete to improve its performance further.

Han et al., (2019) investigated the mechanical properties of recycled polypropylene fiber modified C25 concrete. In their research, concrete specimens were prepared with different fiber content ranging from 0 kg/m^3 to 1.2 kg/m^3. The compressive strength of the recycled polypropylene fiber modified C25 concrete went from approximately 25 MPa to 35 MPa, with the highest strength achieved at an optimal fiber content. Regarding tensile strength, the presence of recycled polypropylene fibers can enhance the concrete's post-cracking behavior and tensile strength. The tensile strength of recycled polypropylene fiber modified C25 concrete was reported to range from approximately 3 MPa to 5 MPa, depending on the fiber content.

In general, fiber reinforced concrete shows a noticeable increase in control of the crack ductility, toughness, impact resistance, fatigue strength, compressive strength, flexural strength, tensile strength, adhesion, bond strength and impermeability, etc.

2.4.2 Partial cement replacement with fly ash in concrete

Literature discussed in this study paper has given an overview of advantages of fly ash concrete to increase workability, strength, and durability of concrete. Here are some reviews of the studies.

Poon and Wong, (1999) from their experimental results concluded that replacement of cement by 15%to 25%by fly ash results in lower porosity of concrete and plain cement mortars. Literature discussed in the review has shown improvement in the workability and durability of concrete by partial replacement of cement with fly ash. However, 28 days strength was reported to be lower by replacement of cement with fly ash, than concrete without replacement of cement with fly ash. Analyzing the literature, it is seen that grinding fly ash is less effective. This may be due to destruction of spherical shape of fly ash which is helpful in increasing workability and reducing voids. Grinding cost also offsets partial cost advantage of cheaper fly ash over cement. Low reactivity of low lime Indian fly ashes as compared to high lime fly ash restricts use of higher volumes of fly ash for cement replacement. Lower reactivity of fly ash makes it urgent to develop a method for replacing higher volumes of cement with fly ash without grinding or activation of fly ash.

Rebeiz et al., (2004) reported an investigation on the use of fly ash as replacement of sand in polymer concrete. In the weight mix design 15% sand was replaced by fly ash. This replacement of 15%sand with fly ash by weight increased compressive strength by about 30%. Also, there was an improvement in the stress strain curve. They also reported good surface finish due to addition of fly ash as replacement of sand which also reduce permeability and have an attractive dark color. Flexural strength of steel reinforced polymer concrete beams was increased by 15%. When subjected to 80 thermal cycle’s polymer concrete with fly ash exhibits slightly better thermal cycling resistance (about 7% improvement) than polymer concrete without fly ash.

Malhotra and Ramezanianpour (1994) discussed the role of supplementary cement materials and super plasticizer in reducing greenhouse gas emissions. The author also discussed different ways of reducing CO_2 emission. With emphasis on developing countries the author discussed that their infrastructure needs lead them to use huge amounts of cements. This huge need for cement can be reduced by replacing cement with easily available good quality of fly ash from the thermal power stations. The author also mentions the development of high performance; high volume fly ash concrete that incorporates large dosages of super plasticizer which enhances the durability of concrete. The paper also discussed about different cementing materials that can be used in concrete making as replacement of cement to reduce the cement consumption and also reduce the CO_2 emission to atmosphere.

Harison et al., (2014), In their study, cement has been replaced by fly ash accordingly in the range of 0% (without fly ash), 10 %, 20 %, 30%, 40%, 50% and 60% by weight of cement for M-25 mix with 0.46 water cement ratio. Concrete mixtures were produced, tested, and compared in terms of compressive strength. It was observed that 20% replacement Portland Pozzolana Cement (PPC) by fly ash strength increased marginally (1.9 % to 3.2 %) at 28 and 56 day respectively. It was also observed that up to 30% replacement of PPC by fly ash strength is almost equal to referral concrete after 56 days. PPC gained strength after the 56 days curing because of slow hydration process.

2.5 Research gap

In recent years, there has been a growing interest in exploring sustainable alternatives in construction materials to reduce environmental impact and enhance the performance of concrete structures. Two promising materials that have gained attention are recycled polypropylene (PP) fibers and fly ash. Recycled PP fibers offer a solution for waste management while providing reinforcement to concrete, and fly ash, a byproduct of coal combustion, can be used as a partial replacement for cement. Individually, these materials have shown favourable effects on the mechanical properties and durability of concrete. However, there is a research gap regarding the combined effect of recycled PP fibers and partial cement replacement with fly ash on ordinary Portland cement (OPC) concrete.

Polypropylene fiber has relatively little impact on the compressive strength of concrete compared to its contribution to tensile and flexural strength. Considering this, a prior study advises examining how alternative secondary cementitious ingredients, such as fly ash or silica fume, could improve the compressive strength of polypropylene fiber-reinforced concrete (Ahmad et al.,2022).

Numerous studies also showed that unideal fiber insertion would affect the consistency, flowability, and workability of concrete blending and result in fiber bonding. Ultimately affecting the reinforcing impact strength characteristics. This uneven addition of fiber to concrete decreases workability depending on various factors, including the maximum aggregate size, fiber volume, type, shape, and aspect ratio (Jaivignesh & Sofi, 2017; Akca & Özyurt, 2018). Finding the right amount proportion of fiber addition is crucial for achieving good workability characteristics of concrete. Therefore, the combined effect of recycled polypropylene fibers and partial cement replacement with fly ash on ordinary portland cement concrete to improve its strength, workability and durability property should be worth looking at.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Introduction

The research design, materials and methods chapter provide a comprehensive understanding of the study's design, procedures, and the characterization techniques employed to analyze the materials used in the research. It outlines the systematic approach taken by the researchers to address the research objectives and ensure the validity and reliability of the study. In this section of paper, its presented a detail overview of the research design, methodology and material characterization techniques employed in this experimental research, aiming to provide clarity and guide readers through the study's procedures.

3.2 Design of study

This research paper aims to investigate the effects of incorporating polypropylene fiber and partially replacing cement (ordinary portland cement) with fly ash in C25 concrete. The research design section provides a comprehensive overview of the study's structure and plan, outlining the research approach, variables under investigation, experimental groups, sample selection, procedures, data collection, and analysis techniques.

The research design follows an experimental approach, allowing us to systematically handle the independent variables (polypropylene fiber content and fly ash replacement proportions) and measure their impacts on the dependent variables (Fresh and hardened properties of concrete). Through careful control of variables and assignment of contestants, it is aimed to minimize bias and ensure the internal validity of the findings.

The independent variables in this study include the amount of polypropylene fiber added to the concrete mix and the percentage of cement replaced with fly ash. These variables were varied across different experimental groups to assess their influence on the dependent variables. The dependent variables encompass various mechanical properties of concrete, such as compressive strength, flexural strength, splitting tensile strength, and its durability characteristics, including water absorption and resistance to chemical attack.

To conduct this research, a sample of concrete specimens was prepared using different combinations of polypropylene fiber content and fly ash replacement ratios. The sample selection process involved selecting appropriate proportion of each constituent, determining the sample size, and criteria for inclusion.

The experimental procedure involves carefully mixing the concrete constituents, casting and curing the specimens, and subjecting them to standardized testing protocols. The properties of the concrete samples, such as strength, durability, and internal structural analysis, was measured and recorded using appropriate testing equipment and techniques.

Data collected from the experimental procedures was analysed using quantitative data analysis technique to assess the relationships between the independent and dependent variables. This analysis will enable us to draw conclusions and make inferences about the effects of polypropylene fiber and fly ash replacement on the performance of C25 concrete.

It is essential to acknowledge the limitations of this research design. These may include constraints related to sample size, generalizability, or the specific characteristics of the experimental setup. By recognizing these limitations, the research aim to provide a balanced perspective on the strengths and weaknesses of the study.

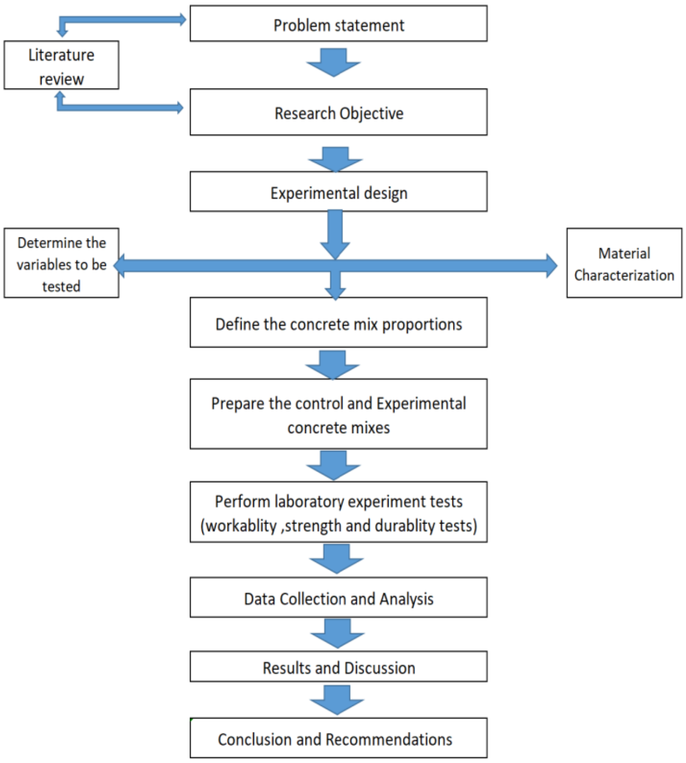


Figure 3.1 Research design flowchart

3.3 Materials

This section discusses the properties of material and their characterization technique used in the research paper. The properties of each material must comply with the standards and specifications. ACI, ASTM and JSTM standards and specifications were used to check the sampling method and testing requirements. Except for chemical tests, all laboratory tests on cement, aggregate and concrete was carried out in the civil engineering and biology laboratories in Adama Science and Technology University. A complete silicate analysis of coal fly ash was conducted in the Geological Survey of Ethiopia.

3.3.1 Cement

Cement is a hydraulic binder and is defined as a finely ground inorganic material, when mixed with water, forms a paste that sets and hardens through hydration reactions and processes which, after hardening, retains its strength and stability even under water. Portland cement is the one that is the most used in Ethiopia for concrete production.

Specification for cement places limits on both its physical properties and, often, chemical composition. Understanding the significance of some of the material properties helps interpret the results of cement tests. Tests of the physical properties of cement should be used to evaluate the properties of cement rather than concrete. Cement specifications limit the properties with respect to the type of cement. Cement should be sampled following ASTM C183/C183M -16, 2013.Ordinary Portland cement was used for this experimental research, which was commercially available in the local market. The cement used is a Type-1 Dangote with a CEM 42.5N grade relative density of 3.15g/cm^3.

Figure 3.2 Dangote OPC cement

Table 3.1 Physical properties of cement

Item No	Description		Test Result
1	Normal consistency test	W/c ratio (%) Water(gm) Penetration(mm)	27 135 5.5
2	Setting time	Initial setting time(min) Final setting time(min)	75 290

The Normal consistency test for Ordinary Portland Cement (OPC) was conducted to determine the amount of water required to produce a cement paste of standard consistency. The test method is specified by ASTM C187. The step-by-step procedure for conducting the normal consistency test for OPC using ASTM standards is attached in appendix A.

Figure 3.3 Normal consistency tests for OPC a) Cement measurement

b) Setting up Vicat's apparatus

The Initial and Final Setting Time tests on Ordinary Portland Cement (OPC) were conducted according to ASTM C191 standard. To begin the Initial Setting Time test, a representative sample of OPC weighing approximately 500 grams was prepared. The Vicat apparatus was set up as per ASTM specifications, including the Vicat mold, plunger, and Vicat needle. Cement paste is prepared by gradually adding water to the OPC sample to achieve the desired water-to-cement ratio. The Vicat mold is then filled with the prepared cement paste, ensuring it is compacted and leveled off. The Initial Setting Time is determined by lowering the Vicat's apparatus with the attached needle onto the surface of the cement paste and applying a steady vertical load. The time at which the needle fails to penetrate the cement paste to a specified point is recorded as the Initial Setting Time which is 75 minutes.

After determining the Initial Setting Time, the test proceeds to the Final Setting Time evaluation. The needle penetration test is continued by periodically repeating the process of lowering the Vicat plunger and observing the needle penetration into the cement paste. The Final Setting Time is recorded when the needle no longer penetrates the cement paste to a specified point. Which was finally found 290 minutes.

3.3.2 Fly ash

Fly ash consists primarily of silicon, aluminium, iron, and calcium oxides. Magnesium, potassium, sodium, titanium, and sulphur are also present to a lesser degree. It can be used as a substitute for Portland cement or a supplement. The makeup fly ash materials are Pozzolanic, meaning they can bind or cement materials together (ACI 232.2R-96.2002).

For this research study, fly ash from the AYKA Addis Textile factory were used, which it is captured and collected by particle filtration equipment(Bag filter) before the flue gases reached the chimneys. The factory uses local coal extracted and supplied from the Achebo area located around Buno Bedele zone of the Oromia region.

Figure 3.4 Fly ash powder

The experimental research contains the information and recommendations concerning the selection and use of class ashes generally conforming to the requirements of ASTM C 618. Complete silicate analysis for chemical composition of fly ash was conducted in the Geological Survey center of Ethiopia and the results of which are given in Table 3.2 The Complete chemical analysis of the Fly ash as reported is attached in the Appendix B section of this study.

According to ASTM C618 (2017), There are two basic types of fly ash: Class F and Class C. Fly ash belong to Class F if the sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ is greater than 70% and belongs to Class C if the sum of the constituents $SiO_2 + Al_2O_3 + Fe_2O_3$ greater than 50% but may be significantly less than the 70 percent of Class F minimum limit. Also, the standard recommendation LOI of the given fly ash should be below 12.

Table 3.2 Complete silicate analysis of fly ash

	Sio_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**MnO**	**P_2O_5**	**TiO**	**H_2O**	**LOI**
Fly ash	50.78	30.42	4.6	<0.01	0.28	0.22	1.08	<.01	0.24	0.64	4.1	8.44

As shown in Table 3.2, the sum of the first three constituents (SiO_2, Al_2O_3, and Fe_2O_3) of coal ash collected from Ayka Addis textile factory is greater than 70%, which indicates that the sample fly ash classified as an ASTM Class F fly ash.

$$SiO_2+Al_2O_3+Fe_2O_3=50.78+30.42+4.6=85.8 > 70\% \text{ (class F)} \quad \ldots\ldots\ldots\ldots \text{(Eq. 3.1)}$$

For particle size distribution, ASTM C618 Standard Specification for coal fly ash and raw or calcined natural pozzolan for Use in Concrete, provides guidelines for the sieve analysis of fly ash. The samples taken from the factory were sieved with sieving equipment before any physical and chemical properties had been determined. The particle size distribution of coal fly ash samples sieved with 300μm, 150μm, 75μm, and 45μm sieves showed as follows.

Table 3.3 Particle size distribution of Fly ash

Sieve size (µm)	**Standard passing As per ASTM C618**	**Percentage retained by mass**	**Percentage Passing of FA**
300	100	0	100
150	70-90	16.6	83.4
75	35-70	21.78	61.62
45	10-40	47.51	14.11
Pan	-	14.11	0

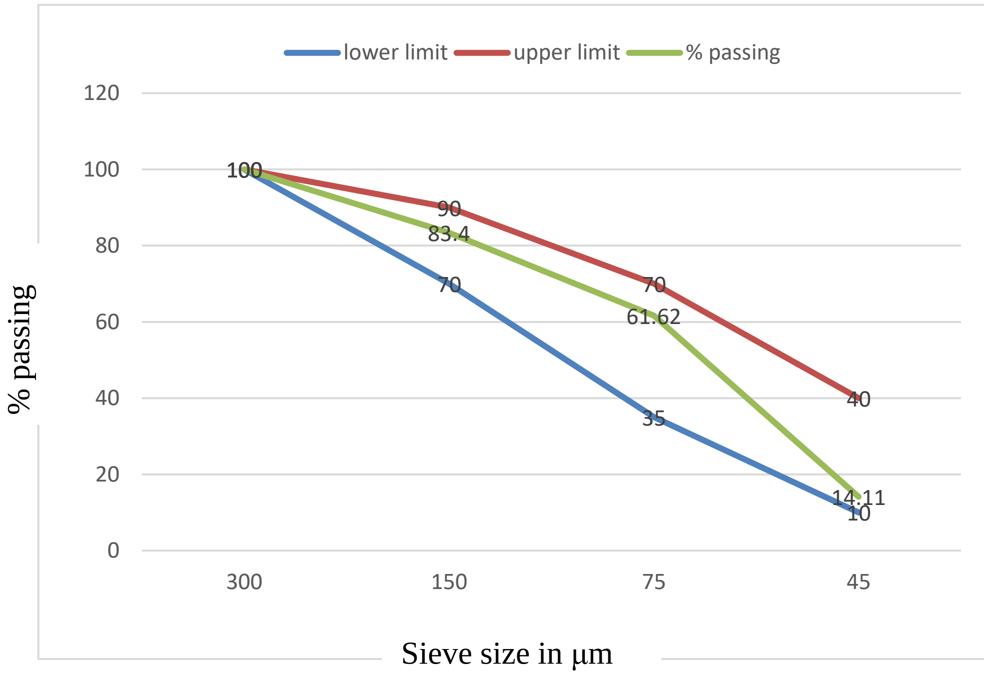


Figure 3.5 Gradation curve of Fly ash

3.3.3 Aggregate

The term aggregate encompasses both fine and coarse aggregates. Aggregates cover three-quarters of the volume of concrete. The same source was used for the aggregate supply to eliminate variations in different sources. All the necessary laboratory tests, such as bulk density, specific gravity, and moisture content of the aggregate, are carried out to warrant that the material meets the specification for the concrete work. The aggregate was washed to remove impurities like silt and any other dust that may cause a quality reduction. A fine aggregate that passes through a 4.75mm sieve was used for this research experiment. Also, basaltic crushed rock coarse aggregate was used for this research, which was obtained from a local aggregate supplier. Coarse aggregates with 9.5mm, 12.5mm, and 19mm were used (ASTM C-33-01,2002).

This study used locally available river sand passing through a 4.75mm sieve. As per ASTM C-125 definition, fine aggregates used in concrete are small-size filler materials that pass through a 4.75mm sieve and retain on sieve 0.07 mm sieve. After the fine aggregate was thoroughly washed and dried, relevant quality tests were conducted in the laboratory to check its compliance with the requirements of specification and standards. Accordingly, the following test results have been recorded (Appendix C).

Table 3.4 Summarized physical Properties of fine aggregate

Item No	**Description**		**Test Result**
1	Silt Content		2.4 %
2	Moisture content		0.83 %
3	Unit weight		1585.29 kg/m^3
4	Absorption capacity		1.01 %
5	Fineness Modulus		2.69
6	Specific gravity	Apparent SSD	2.705
		Bulk(SSD)	2.66

The particle size distribution has been conducted and checked as per ASTM C-136 sieve analysis. A sample of fine aggregate for sieve analysis is first surface dried and then sieved through the series of sieves, starting with 4. 75mm.After shaking, the material retained on each sieve represents the fraction of fine aggregate coarser than the sieve in question and finer than the sieve above. The summation of the material retained on the sieves divided by 100 is called the fineness modulus. It is used as an index to the fineness or coarseness and uniformity of aggregate supplied. A total 500 g sample was taken.

Figure 3.6 Sieve analysis test a) ready sand to be sieved b) sieve analysis test.

The grading requirement for fine aggregate according to ASTM C-33 and the grain size distribution of the fine aggregate is as shown in Table 3.5.

Table 3.5 Particle size distribution of fine aggregate

Sieve size (mm)	**Standard passing As per ASTM C33/AASHTO M6**	**Weight of retained by mass (g)**	**Percentage retained by mass**	**Percentage passing by mass**	**Cumulative Percentage retained by mass**
4.75	95-100	0	0	100	0
2.36	80-100	25	5	95	5
1.18	50-85	75	15	80	20
0.6	25-60	180	36	44	56
0.3	5-30	170	34	10	90
0.15	0-10	40	8	2	98
pan	-	10	2	0	

Fineness modulus of aggregate = (Summation cumulative % retained)/100

= (269/100) = 2.69

Based on grain size distribution of fine aggregate, fineness modulus of fine aggregate would be 2.69 which conform to the both ASTM C-33 and AASHTO M6 requirement. Gradation curve for fine aggregate and standard fineness as per ASTM C-33 presents in Figure 3.6.

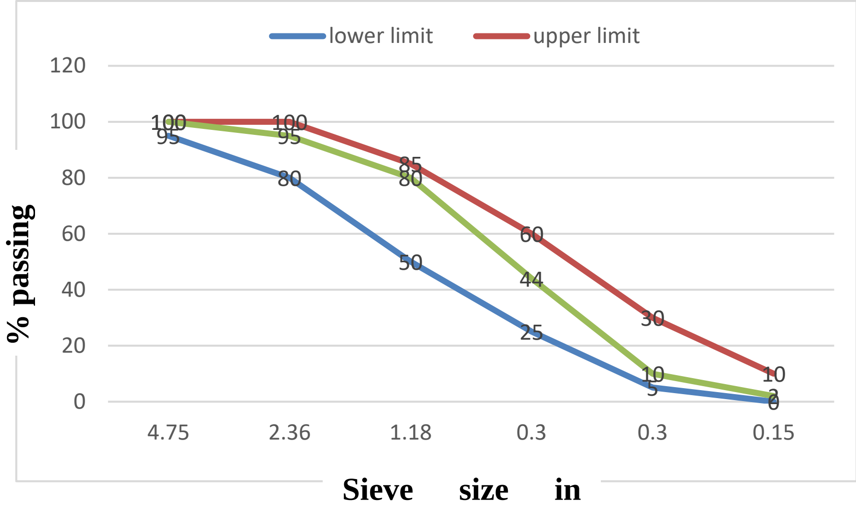


Figure 3.7 Gradation curve of fine aggregate

Specific gravity: is the ratio between the weight of the sand and that of the same volume of water. In this research, apparent specific gravity and Bulk specific gravity of fine aggregate was identified based on ASTM specification. ASTM C128, Standard Test Method for Relative density (specific gravity) and absorption of fine Aggregate, provides guidelines for determining the apparent specific gravity and bulk specific gravity of fine aggregates. The Specific gravity and Absorption capacity found was 2.66 and 1.01% respectively.

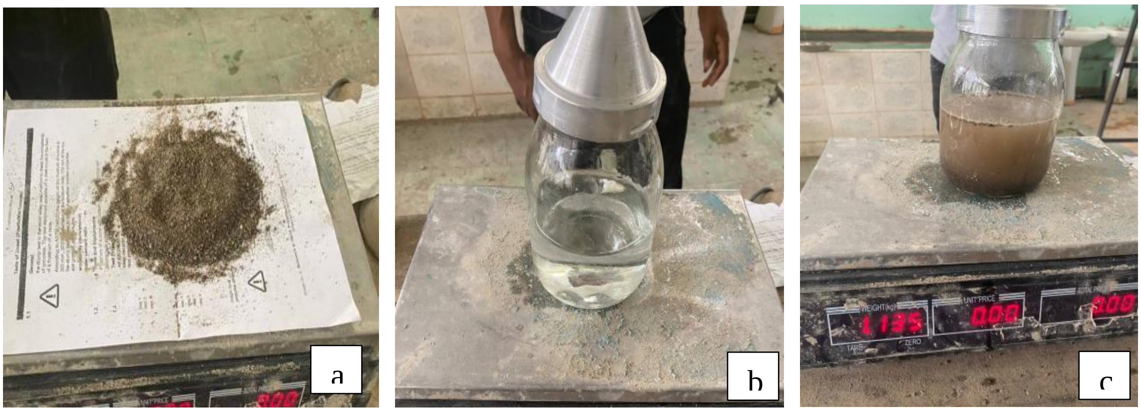


Figure 3.8 Specific gravity and absorption capacity test for fine aggregate a) mass of the sample sand; b) mass of container and water; c) mass of container, water and sand

Silt content: In ASTM standards, refers to the amount of fine particles, specifically silt-sized particles, present in a sample of fine aggregate. Silt particles are intermediate in size between sand and clay, ranging from 0.002 to 0.075 millimeters in diameter. The silt content in fine aggregate is an important parameter to assess the quality and suitability of the aggregate for use in concrete or other construction applications. Excessive silt content can negatively impact the workability, strength, and durability of concrete, leading to potential performance issues.

The silt content test, conducted according to ASTM standards such as ASTM C117, determines the percentage of silt-sized particles in the fine aggregate sample. It involves separating the silt particles from the aggregate through a settling process and measuring the change in water level before and after decanting.

Figure 3.9 Silt content test graduated cylinder

Therefore, to make sure the quality of the sand it is necessary to make a test on the silt content and check against permissible limits. The silt content obtained from the test result is 2.4%, which is between the recommended maximum silt content: 3% to 5%.

Moisture Content: refers to the amount of water present in the aggregate material used in construction. A design water-binder ratio is usually specified based on the assumption that aggregates are inert. However, in most cases, aggregates from different sources do not comply with this. Wet aggregates give water to the mix, and dry aggregates take water from the mixture. In both cases, it will affect the design water-binder ratio. To correct this inconsistency, the fine aggregates' moisture content must be determined.

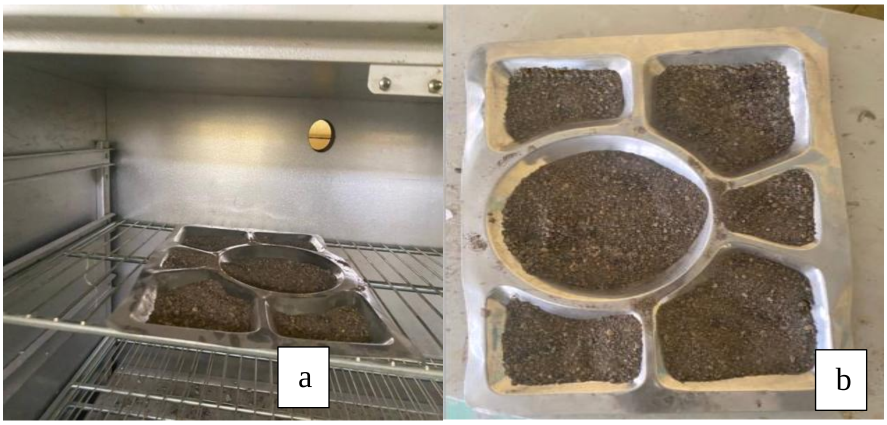


Figure 3.10 Moisture Content test a) sample before oven dry b) sample after oven dry

The procedure outlined in ASTM C566 involves taking a representative sample of the fine aggregate, determining its initial weight, and then drying it in an oven at 110 ± 5°C for 24 hrs. After drying, the sample is cooled, and its final weight is measured. The moisture content is calculated as the difference between the initial and final weights, expressed as a percentage of the dry weight of the sample. The moisture content of the sample was found to be 0.83 %.

Unit weight: ASTM C29, standard test method for bulk density (unit weight) and voids in aggregate provide guidelines for determining the unit weight of fine aggregate. The unit weight, or bulk density, is the aggregate weight per unit volume. It is commonly expressed in kilograms per cubic meter (kg/m^3) or pounds per cubic foot (lb/ft^3).

The test involves filling a container with a known volume of fine aggregate and determining its weight. The unit weight is then calculated by dividing the weight of the fine aggregate by its volume. As a result, the unit weight of sample sand was to be found 1,585.29 Kg/m^3.

On the other hand, a crushed stone with a nominal size of 19 mm from a local source confirming ASTM C-33. For all laboratory experiments, the aggregate was used similarly and purchased once from a single source to avoid the variability of the characteristics of aggregates. Several laboratory tests were conducted to identify the coarse aggregate's physical properties and ensure that the aggregate complies with specific requirements and standards. The physical properties of coarse aggregate used in this research are summarized and tabulated as follows.

Table 3.6 Summarized physical Properties of coarse aggregate

Item No	**Description**		**Test Result**
1	Nominal Maximum Size		19 mm
2	Moisture content		1.27%
3	Unit weight		1513.37 kg/m^3
4	Dry rodded Unit Weight		1605 kg/m^3
5	Absorption capacity		1.52%
6	Specific gravity	Bulk (SSD)	2.65

An excellent aggregate gradation is one of the most critical factors for producing workable concrete. A good gradation secures an increased economy, higher strength, lower shrinkage, and greater durability. Good grading implies that a sample of aggregates contains all standard aggregate fractions in the required proportion such that the sample includes minimum voids. The sieve analysis determines an aggregate's grading or particle size distribution as per ASTM C-136.As shown in Figure 3.6, each size of aggregate fall into the required range of standard passing as per ASTM C-33. A total 2000 g sample was taken.

Figure 3.11 Sieve analysis test for coarse aggregate

Table 3.7 Grain size distribution of coarse aggregate

Sieve size(mm)	Standard passing % As per ASTM C33	Weight of retained by mass	Percentage retained by mass	Percentage passing by mass
25	100	0	0	100
19	90-100	45.6	2.28	97.72
12.5	20-55	1324.44	66.22	31.5
9.5	0-15	371.8	18.59	12.91
4.75	0-5	212.2	10.61	2.3
2.36		46	2.3	0

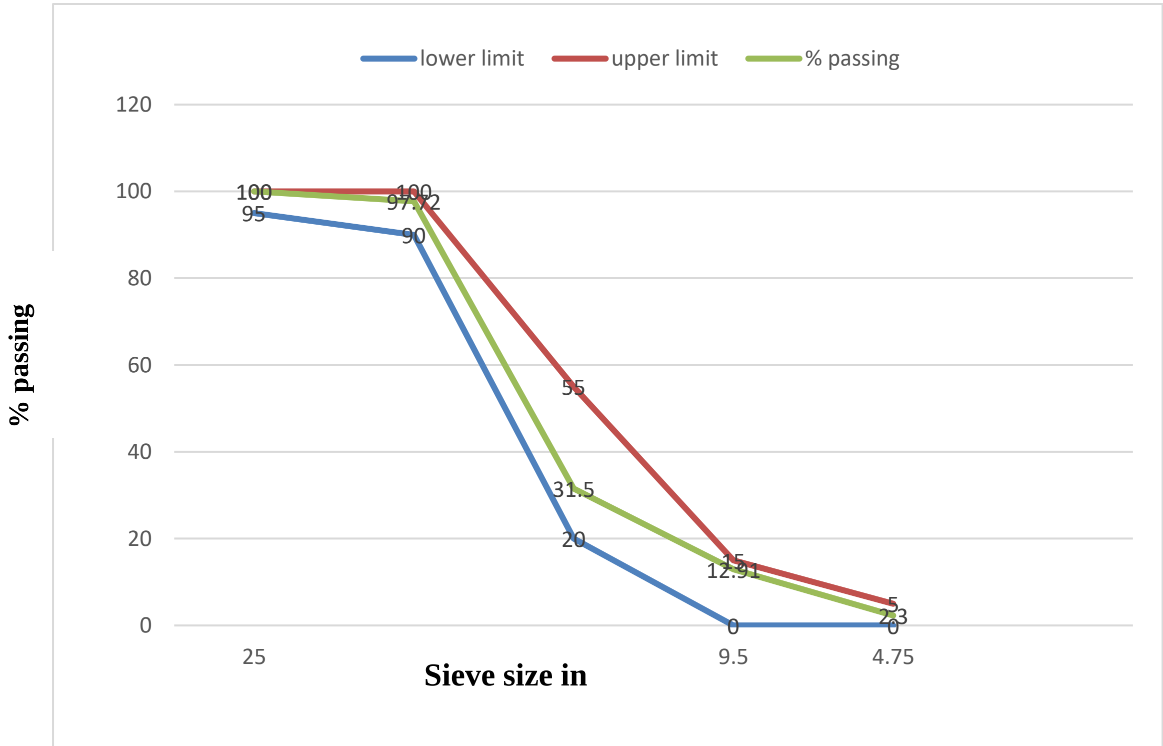


Figure 3.12 Gradation curve of coarse aggregate

Moisture content: According to ASTM C 566, is the test that shows the amount of water or moisture in coarse aggregate. A moisture content of 1.27 % was found as a result.

Unit weight: also known as bulk density and conducted according to ASTM C29. It is the weight of aggregate in each volume of graded aggregate. It includes the aggregate and the void space between the aggregate and the unit weight for normal weight concrete ranges from 1120 to 1920 kg/m^3. The dry rodded unit weight of coarse aggregate is also determined using the ASTM C29/C29M standard test method. The Unit weight and dry rodded unit weight found was 1585.29 Kg/m^3 and 1605 Kg/m^3 respectively.

Specific gravity and absorption test: ASTM C127/C127M-20, standard test method for relative density (specific gravity) and absorption of coarse aggregate, provides the procedure for determining the specific gravity and absorption characteristics of coarse aggregates. The test involves determining the weight of the aggregate in both a saturated surface dry (SSD) condition and in a submerged condition. The standard test also provides a standardized procedure for conducting the specific gravity and absorption test. The test method involves determining the weight of the dry aggregate sample in air and in water, as well as the weight of the saturated surface dry (SSD) aggregate sample in air and in water. The specific gravity and absorption capacity found was 2.65 and 1.52 % respectively.

3.3.4 Water

Given its significant role on the chemical reaction in cement composite, water is an essential ingredient of concrete. It also aids in concrete curing and aggregate cleaning. To avoid low quality water, it should be free of pollutants, alkalis, suspended solids, silt, and dissolved solids. The water used for this study was tap water from the water supply pipeline.

3.3.5 Recycled polypropylene fiber

The recycled polypropylene fiber for this research was made in the Ah-wan plastic factory based in Adama town. These fibers were formed from the post-consumer product of polypropylene plastic waste packaging materials. The physical property is not altered with a specific gravity of 0.91. R-PPF of length about 55 mm (55 ± 5 mm) and 1 mm (1±0.1mm) in diameter was used. This aspect ratio of fiber has been suggested from previous experimental research, standards and guidelines.

The recycling of PP involves several steps, including collection, sorting, cleaning, and reprocessing. The collected PP waste is first sorted to remove contaminants and impurities, such as paper, metals, and other plastics. After sorting, the PP is thoroughly cleaned to eliminate any residual substances. Finally, the cleaned PP is processed through techniques like melting, extrusion, and spinning to produce recycled PP material.

Figure 3.13 Polypropylene plastic materials recycling symbol

Converting recycled PP into fibers typically involves melting the PP material and extruding it through spinnerets to form continuous filaments. The filaments are cooled and solidified to create PP fibers with the desired properties. The recycled PP can produce fibers for various applications, including reinforcement in concrete. The fiber production process may also include additional steps, such as stretching, texturing, or blending with other materials, to enhance specific characteristics (ACI Committee 544, 2015).

3.4 Methods

This section discusses the experimental methods used in this research paper. ACI, ASTM and JSTM standards and specifications was used for checking of requirements in sampling method and testing program. The properties of each material complied with the requirements of standards and specifications.

In order to investigate the combined effect of recycled polypropylene fibers and fly ash replacement of cement in ordinary portland cement composite properties, Cubes (150mm x 150mm x150mm and 70mm x 70mm x 70mm), cylinders (radius 150mm and height 300mm) and beams (500 mm x 100 mm x100 mm) has been casted using a design mix of ACI 211.1-91 for C25 concrete. An effort was made to get the strength of the specimen made up with different percentage of both recycled polypropylene fibers and fly ash. This experimental work include three different contents of the recycled polypropylene fibers

(0.5, 1 and 1.5 wt. % of cement) contents and three different contents of the fly ash (0, 10 and 20 wt. % of cement). These proportions were used based on previous ACI and ASTM standards and specifications guidelines and also from previous related research papers.

3.4.1 Mix design

The mix design was accomplished as per ACI 211.1-91 standard procedures. The mix design is specified for concrete C25. This concrete mix has been chosen for this investigation because it is a versatile and widely used concrete material, making it suitable for most types of structures in residential and commercial construction works. All the concrete mixes was done in the laboratory by using mixer with the ingredients ready to be mixed. The standards in ASTM C192 were used in making and curing the concrete test specimens in the laboratory. At first the coarse aggregate and the fine aggregate was added to the mixer to be blended followed by cement and then the fly ash. The materials were dry blended for a few minutes and two-thirds of the water measured will be added and the mixing continued for another minutes. Finally, the R-PPF was added to the mix and the remaining water will be added so that the ingredients thoroughly mixed until uniform consistency is achieved. The Mix design procedure followed by this experimental procedure is attached in appendix E.

3.4.2 Material proportioning

Material proportioning refers to the process of determining the appropriate quantities or proportions of various materials, such as cement, aggregates, water, and admixtures, to achieve the desired properties of the concrete.

ASTM C618, which covers the use of fly ash in concrete, suggests that fly ash can be used as a partial replacement for cement in the range of 0 % to 40 % by mass of the total cementitious materials. This range suggests a balance between improving concrete performance and achieving sustainability benefits.

Regarding the addition of recycled polypropylene fibers, ASTM does not provide specific recommendations for the percentage of such fiber dosage in concrete. However, general practice from previous research suggests adding fibers in the range of 0.1% to 2% by weight of cementitious materials. The specific percentage within this range can be adjusted based on the desired properties of the concrete, such as improved strength, crack resistance, impact resistance, or durability.

Having mentioned the above, this experimental work used three different proportions of the recycled polypropylene fibers addition (0.5, 1 and 1.5 wt. % of cement) and three different proportion of the fly ash (0, 10 and 20 wt. % of cement).

Table 3.8 Sample mix

Control mix	0% FA and 0% RPPF			
	Fly ash [wt%]			
R-PPF [wt%]		0	10	20
	0.5	0.5%RPPF and 0%FA	0.5%RPPF and 10%FA	0.5%RPPF and 2%FA
	1	0.5%RPPF and 0%FA	1%RPPF and 10%FA	1%RPPF and 20%FA
	1.5	0.5%RPPF and 0%FA	1.5%RPPF and 10%FA	1.5%RPPF and 20%FA

Table 3.9 Mix proportions for RPPF and FA for 0.9514 m^3(Appendix E)

Trial mix name	Trial mix name code	Cement [kg]	Water [kg]	C.A[kg]	F.A[kg]	PP Fiber Content[cement wt%]	PP Fiber [kg] addition	Fly ash cement replace -ments [%]	Fly ash cement replacement [kg]
Control mix 0% FA and 0% RPPF	T 0-0					0	0	0	0
0% FA and 0.5% RPPF	T 0-0.5					0.5	1.807	0	0
0% FA and 1% RPPF	T 0-1					1	3.614	0	0
0% FA and 1.5% RPPF	T 0-1.5					1.5	5.420	0	0
10% FA and 0.5% RPPF	T 10-0.5	361.35	191.48	935.71	706.69	0.5	1.807	10	36.135
10% FA and 1% RPPF	T 10-1					1	3.614	10	36.135
10% FA and 1.5% RPPF	T 10-1.5					1.5	5.420	10	36.135
20% FA and 0.5% RPPF	T 20-0.5					0.5	1.807	20	72.27
20% FA and 1% RPPF	T 20-1					1	3.614	20	72.27
20% FA and 1.5% RPPF	T 20-1.5					1.5	5.420	20	72.27

Before it's casted into the molds, the molds were cleaned and lubricated with machine oil to grease molds inside surfaces with a suitable release agent to prevent it sticking.

Figure 3.14 Cleaning and lubricating molds

The workability has been assessed prior to filling the molds, and a slump test was performed. So, every batch of freshly mixed concrete has been slump measured in accordance with ASTM C-143 to ensure that it is still workable. Then placing the slump cone on the non-absorbent plate or base, Fill the cone with concrete in three layers, each approximately one-third of the cone's height. Using the tamping rod to compact each layer with 25 strokes, evenly distributed over the cross-section.

Figure 3.15 Slump measurement

After checking the workability of concrete, filling the molds, compacting each layer with a suitable compaction tool, that is with a vibrating table compactor has been done in the lab.

Figure 3.16 Compacting molds using vibrating table compactor

After compaction and placing for 24 hrs., samples were removed from their molds to be immersed into a water pond for 7 and 28 days.

Figure 3.17 Sample concrete specimens before and after casting for 24hrs.

According to ASTM C31/C31M standard practice for making and curing concrete test specimens in the field, immersion water curing is one of the recommended methods for curing concrete test specimens. The standard provides guidelines for the preparation, curing, and handling of concrete test specimens in experiments.

Immersion water curing method involves fully submerging freshly cast concrete in water for a 7th and 28th days to promote hydration and achieve proper strength development. This method is commonly used in construction practices to ensure adequate moisture supply and minimize moisture loss during the early stages of concrete curing.

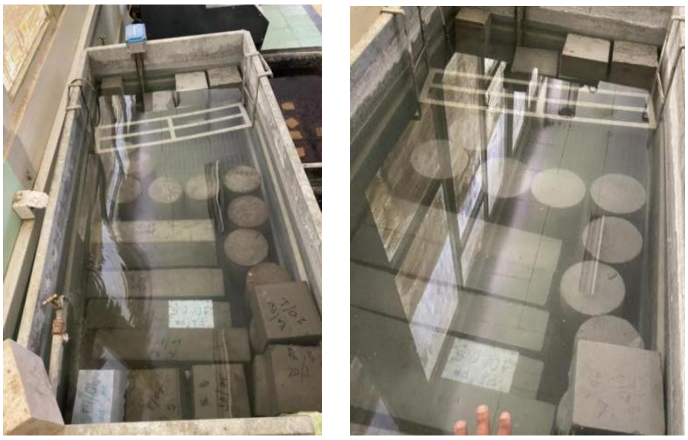


Figure 3.18 Water immersing curing technique

Finally a test was made to get the strength of a specimen made up of a different percentage of both recycled polypropylene fibers and fly ash to the respective strength of conventional concrete at the end of testing days of water immerse curing to have an idea about the optimum percentage of both inputs which does affect the strength of the non-conventional concrete considerably.

3.4.3 Compressive Strength Tests

When the curing time of the concrete specimens was reached, it was taken out of the curing water tank, and the surface dried before its test. The test was held according to ASTM C39.The specimens were first weighed and tested on the 7th and 28th with a compression testing machine. The load was applied gradually with the rate of loading of at the rate of 140 kg/cm^2/minute till the failure stage is reached. For each mix specimen, three cubes were tested at seven and twenty-eight days of concrete age for the combined effects of recycled polypropylene fibers and partial cement replacement with fly ash on ordinary Portland cement concrete with control samples.

For the entire test 60 cube samples were cast on cube with dimensions of 150mm×150mm×150mm. Finally, the compressive strength test was done for each sample mix cast. The compressive strength of the concrete is calculated by dividing the load at failure by the cross-sectional area of the cube. The following equation shows the compressive strength test formula.

$F=P/A$……………………………………………………… (Eq.3.1)

Where, F = Compressive strength of the specimen (in MPa).

P=Maximum load applied to the specimen (in N).

A=Cross sectional area of the specimen (in mm^2)

Figure 3.3 Sample mix cube in compressive testing machine

3.4.4 Splitting Tensile Strength Test

The splitting tensile strength test was conducted to determine the splitting tensile strength of concrete. The splitting tensile strength method consists of applying a diametric compressive force along the length of a cylindrical concrete specimen at a rate of 689 to 1380 kPa /min until failure occurs (ASTM C-496-17). For the test, a control and sample mix of experimental concrete composite recycled polypropylene fiber and partially cement-replaced fly ash mix were prepared with a dimension of a cylinder 150mm in diameter and 300mm in height. The samples were tested for the 7^{th} and 28^{th} days. For all tests, 60-cylinder samples were casted. The following equation shows the splitting tensile strength formula.

$F=2P/\Pi ld$……………………………………………………… (Eq. 3.2)

Where,

F=splitting tensile strength (in MPa)

P=maximum applied load (in N)

l=length of cylindrical specimen (in mm)

d=diameter of cylindrical specimen (in mm)

Figure 3.20 Sample mix cast in splitting tensile strength test machine

3.4.5 Flexural Strength Test

This test aims to determine the flexural strength of the concrete. It is also known as bend strength or modulus of rupture. The test was held according to ASTM C 78–94. Flexural strength represents the highest stress experienced within the material at its moment of yield. The concrete was casted on a mold of a beam member having dimensions of 500 mm in length, 100 mm in width and 100 mm in height. The specimens were first weighed and tested on the 7th and 28th with a flexural testing machine. For all tests, 60 beam samples will be cast. The load was applied gradually with the rate of loading at the rate of 180 kg/minute till the failure stage is reached. Flexural strength is calculated using the equation:

$F=PL/(bd^2)$ …………………………………………… (Eq. 3.3)

Where,

F=Flexural strength of concrete (in MPa)

P=Failure load (in N)

L=Effective span of the beam (mm)

b=Breadth of the beam (mm)

d=Depth of the beam (mm)

Figure 3.4 Flexural strength test a) Beam ready for flexural test b) Beam after flexural test (rapture inside middle third)

3.4.6 Water absorption test

To conduct a water absorption test using ASTM C642, prepare cubes with a side length of 70 mm. Weigh the dried and cooled samples (W_1) using a digital scale to the nearest 0.01 g. Immerse the specimens in room temperature water for 24 hours. Then remove the specimens from the water and wipe off any excess water. Weigh the samples again (W_2) and calculate water absorption using equation 3.4. The step-by-step procedure for conducting water absorption test using ASTM standards is attached in appendix G.

Water absorption (%) = $[(W_2-W_1)/W_1] * 100$…………………………………… (Eq. 3.4)

Where:

W_2 is the weight of the specimen after immersion in water

W_1 is the weight of the specimen before immersion in water

Figure 3.22 Dried sample cubes in an oven

3.4.7 Sulfate attack test

ASTM C1012-18, "Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate solution "provides a method for evaluating the sulfate resistance of concrete cubes through mass loss measurements. This test method assesses the durability of concrete against sulfate attack, which can cause significant deterioration and weakening of the material in sulfate-rich environments. However, this method is for mortar, and the behavior of mortar and concrete under chemical attack might not be the same. One of the ways of knowing the deterioration mechanism of concrete under the exposed chemical solution is the mass loss method as shown by equation 3.5 (Devi et al., 2017; Shirayma and Yoda, 1991).

In order to get the accelerated degradation process and to shorten the test duration, changing the concentration of the sulfate solution in a way that simulates the highest sulfate concentrations can be done (Van et al., 2013). The lower limit of the exposure proposed by the ASTM C1012 test method is the use of 50 g/L Na_2SO_4 concentration in water solution. For this sulfate chemical attack experimental study, Japanese Industrial Standard for chemical resistance of concrete in aggressive solution JSTM C7401 testing method was used. This test method assesses the chemical resistance of concrete by immersing test specimens into acid or alkaline solutions for a prescribed period and by comparing changes in the measurements against control specimens. The sulfate resistance of concrete can be quantified by measuring changes in weight occurring in specimens stored in chemical solutions (McCarthy & Thomas, 2019).

Figure 3.23 A bottle of Sodium sulfate

In this experimental investigation, cubes of concrete of side 15cm, which were cured for 28 days, were used. After the final day of curing, the specimens were removed from the water, and the excess film of water on the surface was cleaned using a standard preliminary surface cleaning process and weighed as initial mass. Then the identified specimens were immersed in the 5% sulfate chemical solutions (Sodium sulfate solution) for another 28 days. After the immersion period, the specimens were removed from the solution and their final weight was recorded (Appendix H). Then, sulfate and chloride resistance of the specimens in terms of weight loss was determined using the following equation.

$$\text{Weight loss (\%)} = [(W_2-W_1)/W_1] *100 \qquad \text{(Eq.3.5)}$$

Where:

W_2 is the weight of the specimen before immersion in test solution.

W_1 is the weight of the specimen after immersion in test solution.

Figure 3.24 Cubes during and after immersed in sodium sulfate solution.

3.4.8 Micro-structural analysis tests

Understanding of the structure and properties of the individual components of concrete and their relationship to each other helps exercise some control over the material's properties. The type, amount, size, shape, and distribution of phases present in a solid constitute its structure. The gross elements of the system of material can readily be seen, whereas the finer details are usually resolved with the help of a microscope. The term macrostructure is generally used for the gross structure visible to the human eye. The unaided human eye's resolution limit is approximately one-fifth of a millimetre (200µm). The term micro-structure is used for the microscopically magnified portion of a macrostructure. The magnification capability of modern electron microscopes is 105 times; thus, the application of transmission and scanning electron microscopy techniques has made it possible to resolve the structure of materials to a fraction of a micrometre. Progress in the field of materials has resulted primarily from the recognition that the properties of a material originate from its internal structure; in other words, the properties can be modified by making suitable changes in the design of a material. Although concrete is the most widely used structural material, its structure is heterogeneous and highly complex (Kumar & Paulo, 2001).

Scanning Electron Microscopy (SEM) is a test procedure that inspects a sample with an electron beam to produce a magnified image for investigation. High-magnification electron microscopy has high-resolution images and accurately quantifies microscopic objects and features. This technique, commonly referred to as SEM analysis and SEM microscopy, is beneficial for failure and micro-analysis of solid inorganic materials. A concentrated stream of high-energy electrons is employed in scanning electron microscopy to produce different signals at the surface of solid specimens. Most SEM microscopy applications capture data over a chosen region of the sample's surface. A two-dimensional image displays spatial variations in properties, Including chemical characterization, texture, and materials orientation. The SEM can also perform analyses of selected point locations on the sample. This method helps determine chemical compositions, crystalline structure, and crystal orientations in a qualitative or semi-quantitative manner (Laboratory Testing Inc., 2022).

SEM works by using an electron beam that penetrates deep into a sample with about one μm. The beam of the SEM centred toward a point, followed by signals read by detectors that were then converted into intensities to create an image on the attached computer. These signals produce surface topography information in a secondary electron signal image. The signals are created due to the beam hitting valence electrons emitted from the atom. The valence electrons are attracted to a detector. The latter produces a signal proportional to the number of attracted electrons (Chancey, 2008).

The scanning electron microscope (SEM) is one of the most versatile instruments available for the examination and analysis of the microstructure morphology and chemical composition characterizations (Zhou et al., 2006). For this experiment, scanning electron microscopy is used to investigate the morphology of shape, size, and texture of a control and modified concrete with recycled polypropylene fibers addition and partial OPC cement replacement with fly ash concrete (10% fly ash and 1% PP) , which are important to study the micro structural property.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Introduction

The result and discussion chapter evaluate the effects of partial cement replacement with fly ash and the addition of recycled PP fiber on the fresh and hardened strength of concrete. The study aims to investigate the potential enhancements in concrete properties and the optimal combination of fly ash and PP fiber for improved performance.

4.2 Slump test result

The slump test is an important measure of the workability and consistency of fresh concrete. A total of ten mixes were designed with varying level of cement replacement with fly ash and recycled pp fiber addition but keeping average workable water to cementitious ratio of 0.52. Figure 4.1 shows the results obtained in the slump test.

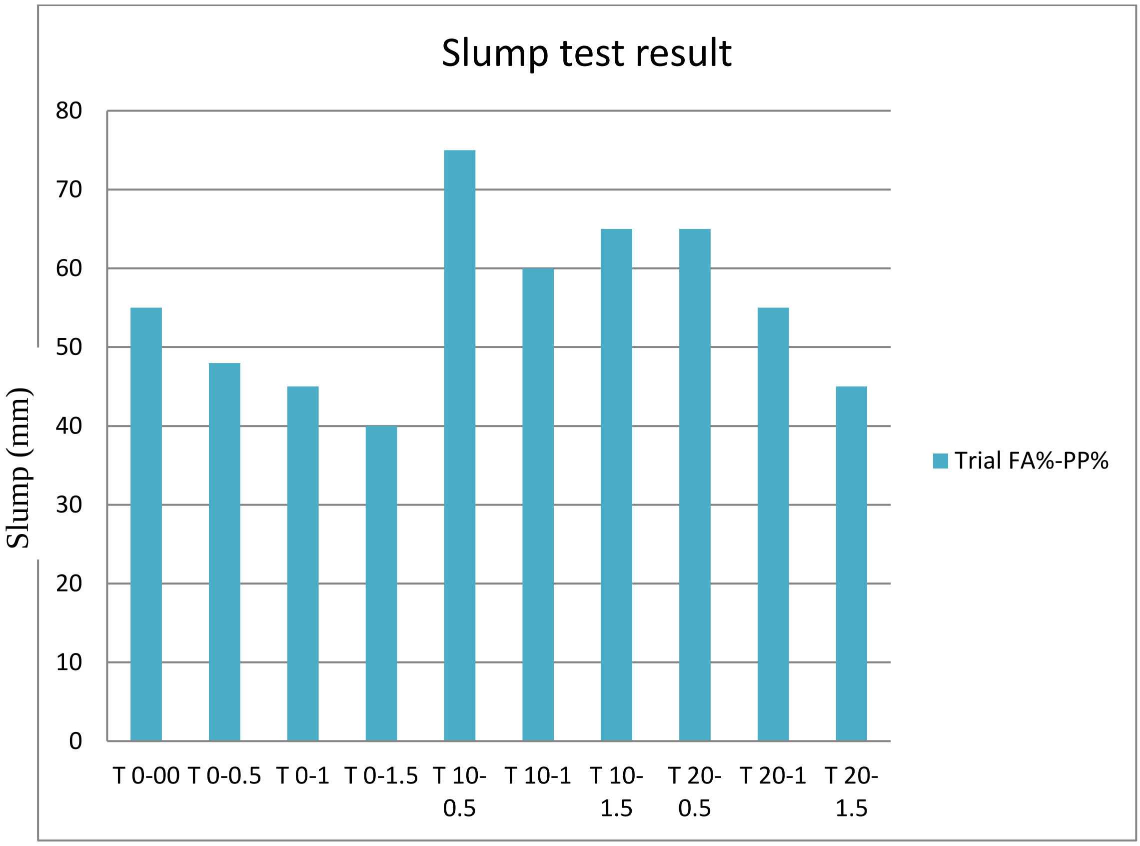


Figure 4.1 Slump test result

The slump test results for each mixture are presented above. The control mixture without any fly ash or PP fiber addition exhibited a slump value of 55 mm. Keeping the average workable water to cementitious ratio constant, as the percentage of fly ash increased, the slump values decreased. Since the extra added fly ash in the mix requires additional water to maintain the desired consistency or workability. Fly ash particles are finer than cement particles and have a greater surface area, which can absorb more water. This absorption of water by fly ash particles can result in a higher water demand in the mix. On the other hand, the mixture with 0% fly ash content and 1.5% PP fiber addition showed the lowest slump value of 40 mm, indicating a less workable consistency compared to other mixtures. The results of the slump tests indicate that the addition of recycled PP fiber only to concrete can significantly reduce the slump. This is because PP fibers are long and slender, and they can interfere with the flow of concrete.

Nevertheless, the addition of fly ash can counteract the effects of PP fibers on slump and resulted in an increase in slump values. This is because fly ash is a pozzolanic material, and it can react with the cement to form a gel that fills the voids in the concrete. This makes the concrete more cohesive and less likely to slump. The mixtures containing 0.5% and 1% PP fibers with 10%fly ash showed higher slump values of 75 mm and 60 mm, respectively. This suggests that the addition of fly ash improved the workability by enhancing the flowability of the concrete.

The findings of this test demonstrate the potential of using fly ash as a cement replacement and incorporating recycled PP fibers to modify concrete properties. The use of fly ash can contribute to sustainable practices by reducing the demand for cement and improving the long-term durability of concrete. These results provide valuable insights for concrete producers and engineers in optimizing mix designs and considering eco-friendly alternatives in construction projects.

4.3 Compressive strength test

The experimental program involved preparing concrete specimens with varying proportions of fly ash and recycled PP fiber. The control mixture consisted of 0 % fly ash and 0 % PP fiber. Additional mixtures included 0 %, 10 % and 20 % cement replacement with fly ash, along with 0.5 %, 1 %, and 1.5 % recycled PP fiber content. The compressive strength was tested on the 7th and 28th day to assess early-age performance and long-term strength development.

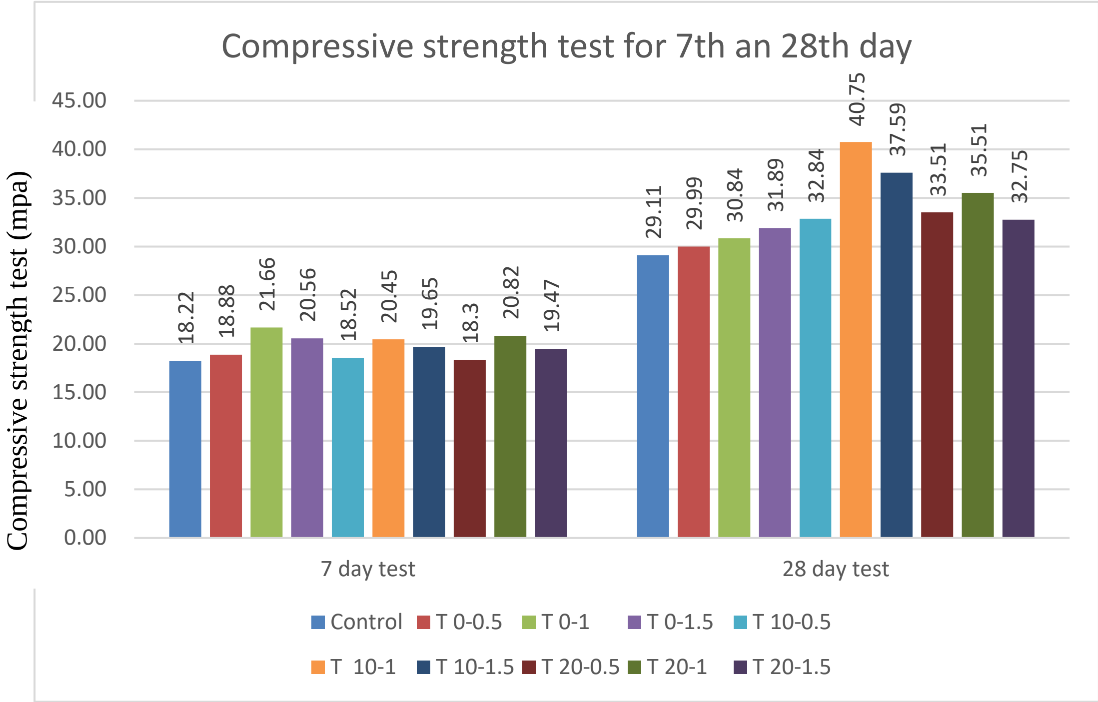


Figure 4.2 Compressive strength test

The inclusion of fly ash in concrete mixtures is often aimed at improving various properties, such as workability, durability, and sustainability. The results obtained in this study indicate that at the tested replacement FA levels (10% and 20% cement replacement) for the compressive strength at the 7th day did not show a significant increase compared to the control mixture. This suggests that the early-age strength development may not be influenced greatly by the addition of fly ash alone. It is important to note that the compressive strength results obtained at the 7th day may not fully represent the long-term performance of the concrete, as fly ash is known to exhibit pozzolanic properties that contribute to strength development over time.

In contrast to the limited effect of fly ash on compressive strength, the addition of recycled PP fiber in the concrete mixtures showed a minor impact on the early-age strength properties. The inclusion of 0.5% recycled PP fiber without fly ash resulted in a slight increase in compressive strength compared to the control mixture. This can be attributed to the fiber's ability to provide internal reinforcement and reduce cracking potential.

The 28th-day compressive strength results demonstrate a significant improvement in strength for most of the modified concrete mixtures. The control mixture without recycled PP fiber and FA exhibited a moderate increase in strength over time. However, the mixtures incorporating both fly ash and recycled PP fiber combinations displayed substantial strength gains. Mixture with 10% fly ash replacement and 1% PP fiber exhibited the highest compressive strength among all the combinations (40.75 mpa) which is 39.99% increase in strength compared to control mix. This suggests a combined effect between fly ash and recycled PP fiber, where the pozzolanic properties of fly ash, such as improved cementitious reactions and densification, are enhanced with the reinforcing properties of PP fiber. This combination contributes to increased long-term strength development, indicating the potential for optimizing concrete mix designs by incorporating both fly ash and recycled PP fiber.

4.4 Split tensile strength test

The experimental program involved preparing concrete specimens with varying proportions of fly ash and recycled PP fiber. The control mixture consisted of 0% fly ash and 0%PP fiber. Additional mixtures included 0%, 10% and 20% cement replacement with fly ash, along with 0.5%, 1%, and 1.5% recycled PP fiber content. The testing data obtained at the 7th and 28th days is analysed to evaluate the effects of different mixtures on the tensile strength performance.

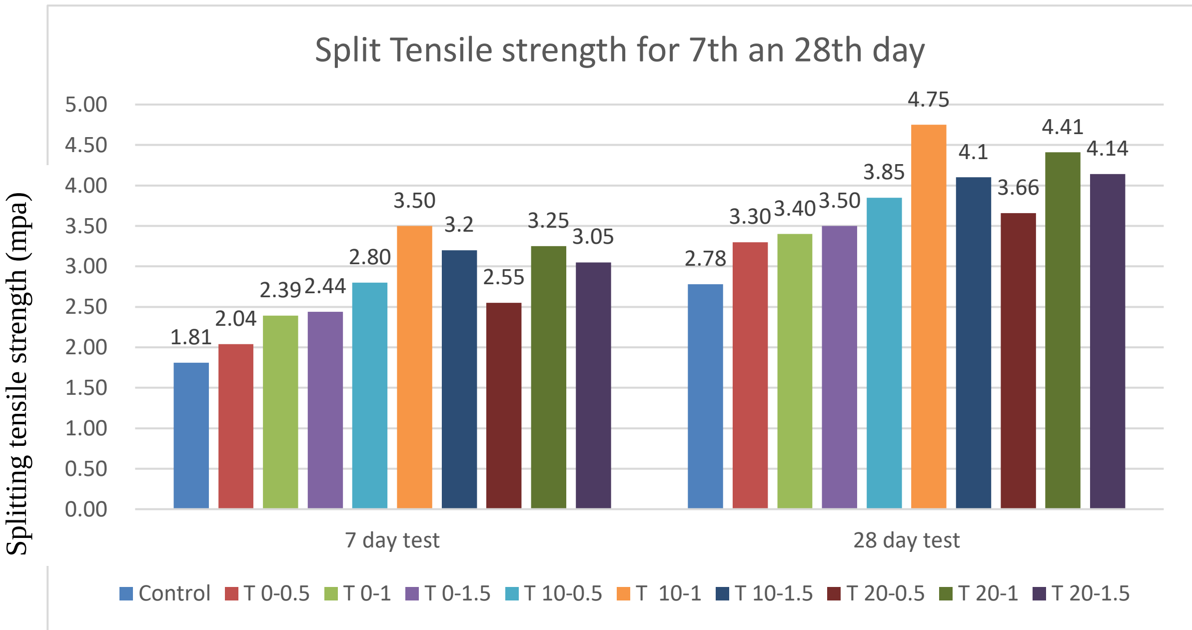


Figure 4.3 Split tensile strength test result

In the analysis of the data for the concrete modification with partial cement replacement and addition of recycled PP fiber, the tensile strength results for the 7th and 28th day testing provide valuable insights into the performance of the modified concrete. Both The 7^{th} and 28^{th} day results show a gradual increase in tensile strength with the addition of PP fiber only. This can be attributed to the enhanced bonding and reinforcement provided by the incorporation of the recycled PP fiber, which improves the overall tensile behavior of the concrete.

Moving to the 28th day results, further improvements in tensile strength were observed, indicating the continued development and maturation of the concrete. The mixtures with fly ash and PP fiber continued to exhibit higher tensile strength compared to the control mixture. The combination of 10% fly ash and 1% PP fiber showed the highest tensile strength value of 4.75 MPa which is 52.73 % increase in strength compared to control mix. This demonstrates the long-term effectiveness of the concrete modification in enhancing the tensile properties and the potential for achieving superior performance over time. Notably, the mixtures with 10% fly ash and 1% PP fiber consistently exhibited higher tensile strength values compared to other mixtures.

The overall test result suggests that the addition of fly ash and PP fiber can effectively enhance the tensile strength of the C25 concrete. The fly ash acts as a pozzolan, contributing to improved hydration and interlocking of the cementitious matrix, while the PP fiber provides additional reinforcement to resist cracking and distribute stress. The synergy between the two modifiers is evident in the results, as the mixtures with higher fly ash content and optimal PP fiber percentage consistently outperformed the control mixture. These findings support the use of fly ash as a sustainable cement replacement and the incorporation of recycled PP fiber as a means to enhance the mechanical properties of the concrete.

4.5 Flexural strength test

Flexural strength is another critical property of concrete, especially in applications where the material is subjected to bending or deflection. The experimental research aimed to determine the impact of incorporating fly ash and recycled PP fiber on the flexural strength of concrete. The mixtures included various combinations of fly ash percentages (0 %, 10 %, and 20 %) and PP fiber contents (0.5 %, 1 %, and 1.5 %).

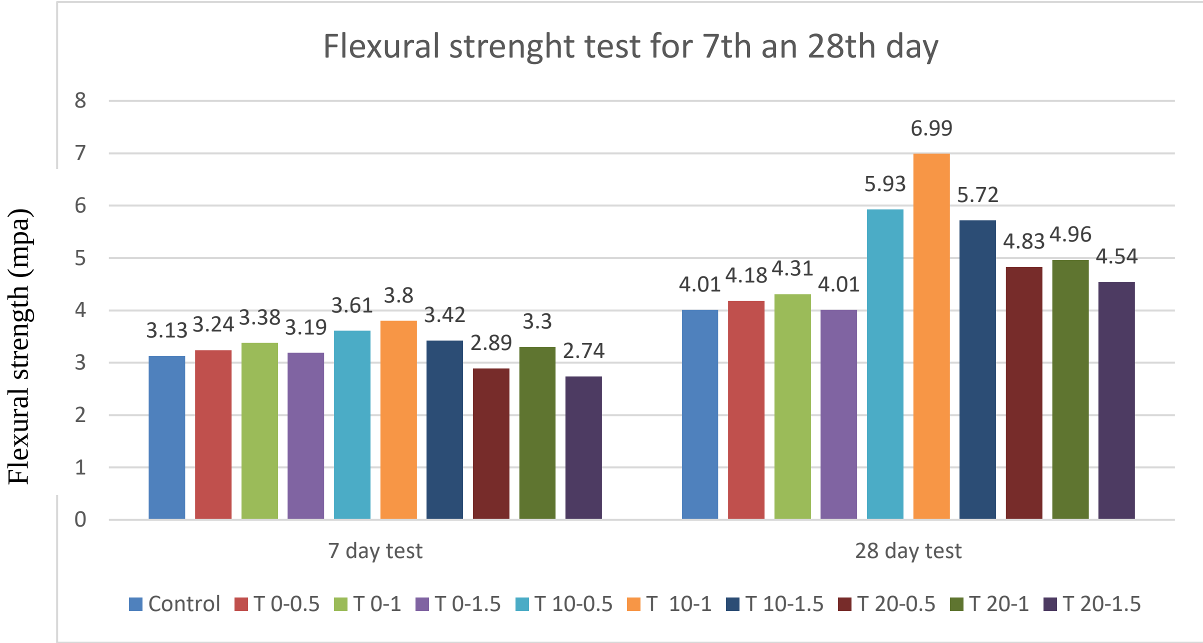


Figure 4.4 Flexural strength test result for 7th and 28th day

On the 7th day, the control mixture (0%fly ash, 0%PP fiber) exhibited a flexural strength of 3.13 MPa. When recycled PP fiber was introduced without any fly ash, the flexural strength slightly increased, with values of 3.24 MPa for 0.5%PP fiber, 3.38 MPa for 1%PP fiber, and 3.19 MPa for 1.5% PP fiber. This indicates that recycled PP fiber alone had an impact on enhancing the flexural strength of the concrete at this early age.

However, when both fly ash and PP fibers were incorporated, significant improvements in flexural strength were observed. The mixtures containing 10% fly ash showed higher flexural strength compared to the control mixture, with values of 3.61 MPa (15.33% increase), 3.8MPa (21.40%increase), and 3.42 MPa (9.26%increase) for 0.5%, 1%, and 1.5% PP fiber additions, respectively. Similarly, the mixtures with 20% fly ash content exhibited enhanced flexural strength, ranging from 2.89 MPa to 3.3 MPa for the same PP fiber additions.

At the 28th day, the trend of increased flexural strength with fly ash and PP fiber additions became more prominent. The control mixture achieved a flexural strength of 4.01 MPa, while the mixtures with fly ash and 0.5%PP fiber showed improvements, ranging from 4.18 MPa to 5.73 MPa for different fly ash percentages. The mixtures with 1%PP fiber additions demonstrated even higher flexural strengths, ranging from 4.31 MPa to 6.99 MPa (7.48%-74.31% increase from control) for different fly ash percentages.

The addition of both fly ash and PP fiber has a cooperative effect on the flexural strength of concrete. This means that the combined effect of the two materials is greater than the sum of their individual effects. Both can improve the flexural strength and ductility of concrete. This makes concrete more durable and resistant to damage, which can extend the lifespan of concrete structures.

4.6 Water absorption test

The water absorption test is conducted to assess the porosity and permeability of a concrete material. The test was conducted to determine the water absorption characteristics of a concrete cube with a side length of 70 mm. A representative cubes were prepared for each mix types and it was subjected for the absorption test.

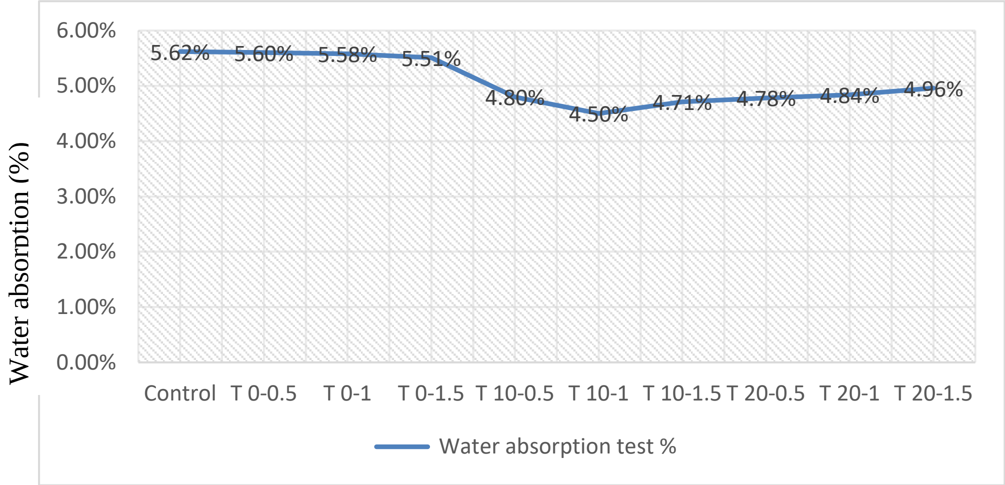


Figure 4.5 Water absorption test result

Upon analyzing the data, it is evident that the introduction of fly ash and recycled PP fiber in the concrete mixture has a noticeable effect on reducing water absorption. The control mixture, without any fly ash or PP fiber, exhibits the highest water absorption value of 5.62%. As the percentage of PP fiber increases with no-fly ash, there is a slight consistent decrease in water absorption, indicating that the addition of PP fiber enhances the concrete's resistance to moisture penetration. This can be attributed to the ability of PP fibers to create a network within the concrete, reducing the pathways for water ingress.

Furthermore, the inclusion of fly ash in the mixture also contributes to reducing water absorption. Comparing the mixtures with the same percentage of PP fiber, it is observed that as the fly ash content increases, the water absorption decreases. This suggests that fly ash, which is a pozzolanic material, contributes to the formation of additional hydration products and denser microstructure, thereby reducing the capillary porosity and water absorption capacity of the concrete.

The lowest water absorption value of 4.5%is achieved in the mixture with 10% fly ash and 1% PP fiber. This combination of partial cement replacement with fly ash and the addition of recycled PP fiber demonstrates the most significant improvement in water absorption resistance, indicating a more durable and moisture-resistant concrete.

The water absorption test results demonstrate that the modification of C25 concrete with partial cement replacement using fly ash and the addition of recycled PP fiber positively influences the concrete's water absorption properties. The inclusion of PP fiber and fly ash leads to a reduction in water absorption, indicating improved resistance to moisture penetration. These findings highlight the potential of incorporating fly ash and recycled PP fiber as effective measures for enhancing the durability and performance of concrete in terms of moisture resistance.

4.7 Sulfate attack test

In this analysis test sulfate attack using sodium sulfate solution were conducted for different concrete mixtures. This experimental research focuses on a concrete modification technique involving partial cement replacement with fly ash and addition of recycled PP fiber. The sulfate attack test helps to evaluate the resistance of these modified concrete mixtures against sulfate-induced deterioration.

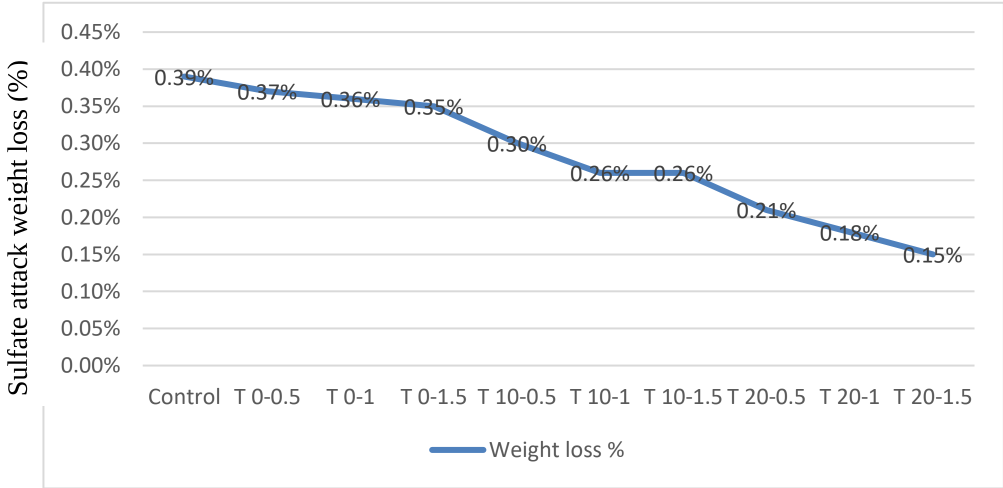


Figure 4.6 Sulfate attack test result

The incorporation of fly ash in the modified C25 concrete mixtures has shown a positive influence on sulfate resistance. As the fly ash content increases from 0 % to 20%, there is a significant decrease in weight loss percentages. This suggests that fly ash acts as a pozzolanic material, reacting with calcium hydroxide to form additional calcium silicate hydrate (C-S-H) gel, which improves the concrete's resistance to sulfate attack. The highest reduction in weight loss is observed in the mixtures with 20 % fly ash content, indicating that higher fly ash content provides better protection against sulfate deterioration.

The addition of recycled PP fibers to the modified C25 concrete mixtures has also shown a significant impact on sulfate resistance. As the percentage of PP fibers increases from 0.5 % to 1% and 1.5%, there is a gradual decrease in weight loss percentages. This can be attributed to the ability of PP fibers to reinforce the concrete matrix and prevent cracking, thereby reducing the ingress of sulfate ions. The presence of PP fibers acts as a physical barrier and improves the overall durability of the concrete, leading to reduced sulfate attack.

When fly ash and PP fibers are combined in the modified C25 concrete mixtures, there is a synergistic effect on sulfate resistance. The weight loss percentages are further reduced compared to individual additions of fly ash or PP fibers. The mixtures with 10% and 20% fly ash content, along with 0.5% to 1.5% PP fiber content, exhibit the lowest weight loss percentages. This suggests that the combined action of fly ash and PP fibers enhances the concrete's resistance to sulfate attack, providing a more effective barrier against the ingress of sulphates.

4.8 Scanning Electron Microscopy (SEM) analysis result

SEM (Scanning Electron Microscope) images provide valuable insights into the microstructure of materials, including concrete. SEM analysis was conducted to examine the surface morphology and micro-structural characteristics of the concrete specimens of a control C25 concrete and a modified C25 concrete with 10% fly ash (FA) cement replacement and 1% recycled polypropylene (PP) fiber addition. The purpose is to analyse the effect of incorporating fly ash and PP fiber on the microstructure of the concrete and identify any notable differences.

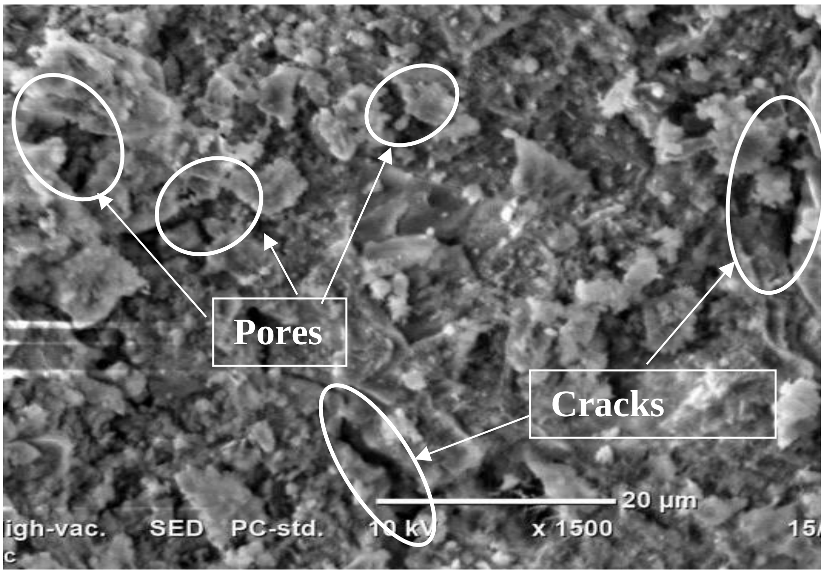


Figure 4.7 SEM image for control C25 concrete

The SEM image of the Control C25 Concrete reveals a typical microstructure of cementitious materials. The cement paste matrix appears relatively less dense and homogeneous, with dispersed cement particles and hydration products. The aggregate particles are bonded with the cement paste, forming a solid network. The interfacial transition zone (ITZ) between the aggregate and cement paste is evident, showing a transition from a packed matrix to a porous region. This ITZ is a critical area for understanding the bond strength and overall mechanical properties of the concrete.

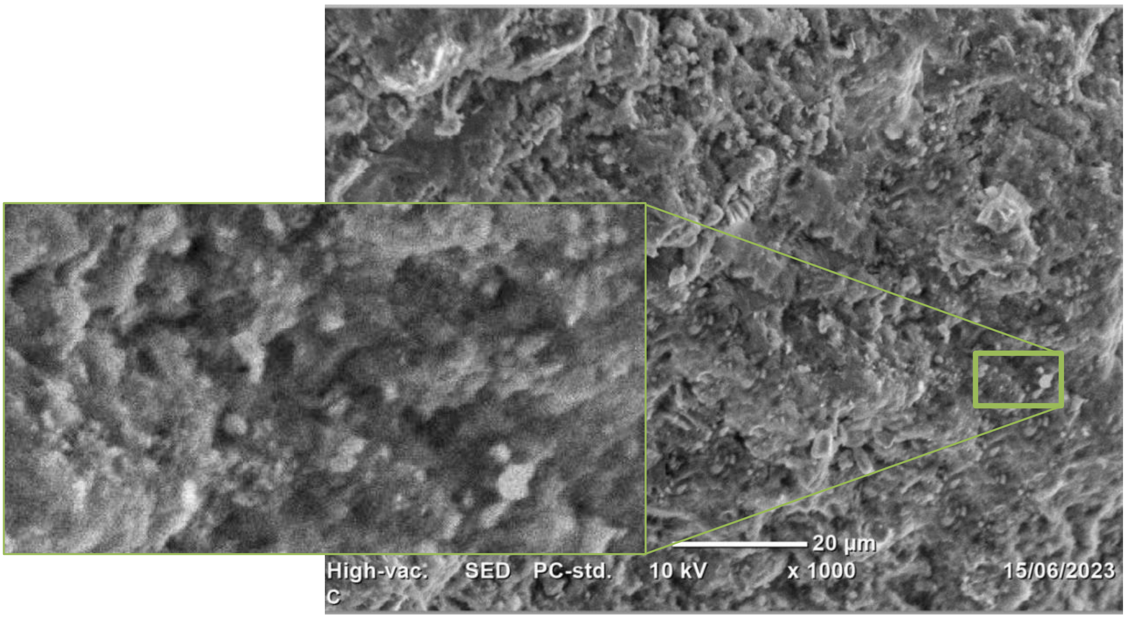


Figure 4.8 SEM image for Modified C25 Concrete (10% FA and 1% PP)

In the SEM image of the experimental concrete with 10% fly ash and 1% PP fiber, several distinct differences can be observed compared to the Control C25 Concrete. First, the presence of fly ash is evident by the formation of additional hydration products within the cement paste matrix. The fly ash particles react with calcium hydroxide during the pozzolanic reaction, resulting in the formation of calcium silicate hydrate (C-S-H) gel. This gel contributes to densification and fills the voids in the concrete, resulting in a more compact microstructure.

Compared to the Control C25 Concrete, the modified concrete with fly ash and PP fiber exhibits a reduced number and size of pores. This reduction in porosity can be attributed to the pozzolanic reaction of fly ash, which fills the voids and contributes to the densification of the matrix. The PP fibers also play a role in reducing porosity by bridging gaps and limiting the formation and propagation of cracks. The decreased porosity improves the durability of the concrete by reducing permeability and enhancing resistance to aggressive agents such as moisture and chemical substances.

Furthermore, the inclusion of PP fibers was observed to create a network-like structure within the concrete matrix. The fibers were evenly dispersed and exhibited good adhesion to the cementitious matrix, enhancing the crack resistance and ductility of the concrete. In the modified concrete, the presence of PP fibers can be seen intercepting cracks and creating a network within the matrix. These fibers act as reinforcement, providing additional resistance to crack formation and propagation.

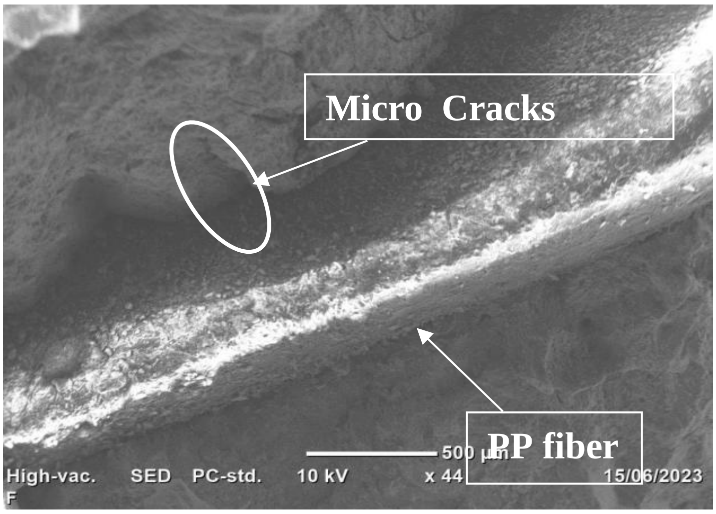


Figure 4.9 Concrete matrix fiber

The cracks observed in the SEM image are generally shorter and narrower compared to the Control C25 Concrete, indicating improved crack control and enhanced tensile properties. The combination of fly ash and PP fiber effectively limits crack width and minimizes the potential for crack growth, which contributes to increased durability and structural integrity of the concrete. In conclusion, the modified C25 concrete with 10% fly ash cement replacement and 1% PP fiber addition demonstrated distinct micro-structural improvements compared to the control concrete. The presence of fly ash led to enhanced packing density and reduced porosity, while the addition of PP fibers contributed to increased crack resistance and improved ductility.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

This chapter summarizes the main findings of the study and draws conclusions based on the results and analysis. It also discusses the implications of the findings, their significance in the context of the research area, and potential applications. Recommendations are also provided for future research directions or practical implementations based on the study's outcomes and offering a road map for future work in the field.

5.1 Conclusion

Based on the findings of this study, the following conclusion was drawn based on the experimental tests: -

- The slump test results indicate that adding recycled PP fiber only to concrete can significantly reduce the slump. Nevertheless, adding fly ash can counteract the effects of PP fibers on the slump and increase slump values. Generally, it can be concluded that adding fly ash improved the workability by enhancing the flowability of the concrete.

- The combined effect between fly ash and recycled PP fiber at a later age is much improved with the pozzolanic properties of fly ash, adding cementitious reactions and densification, and enhanced with PP fiber's reinforcing properties.

- The split tensile strength test result shows that adding fly ash and PP fiber can effectively enhance the tensile strength of the experimental concrete. The fly ash acts as a pozzolan, contributing to improved hydration and interlocking of the cementitious matrix, while the PP fiber provides additional reinforcement to resist cracking and distribute stress.

- The addition of both fly ash and PP fiber has a cooperative effect on the flexural strength of concrete too. The trend of increased flexural strength with fly ash and PP fiber additions became more prominent at later age strength development. Recycled PP fiber provides additional tensile reinforcement and better bonding to resist cracking and distribute stress, while the fly ash, contributing to the improved hydration and interlocking of the cementitious matrix.

- In the water absorption test, the hydrophobic property of R-PPF, helped to prevent water from coming into contact by creating a network within the concrete. Also, fly ash's additional hydration products and denser microstructure, reduce the concrete's capillary porosity and water absorption capacity. Overall, test results demonstrate that the experimental concrete with partial cement replacement using fly ash and the addition of recycled PP fiber positively influences the concrete's water absorption properties.

- The incorporation of fly ash in the experimental concrete mixtures has positively influenced sulfate resistance. As the fly ash content increases, there is a significant decrease in weight loss percentages. Additionally, the non-polar nature of PPF prevents it from reacting with sulfate ions and reinforcing the concrete matrix by averting cracks, and further enhancing its resistance to sulfate attack.

- Adding recycled PP fibers to concrete mixtures has also significantly impacted sulfate resistance. As the percentage of PP fibers increases, there is a gradual decrease in weight loss percentages. This can be associated with the ability of PP fibers to reinforce the concrete matrix and prevent cracking, thereby reducing the ingress of sulfate ions. Sulfate ions are negatively charged, making them more likely to react with cations, particularly those with positive charges. PP fiber is non-polar, which means that it does not have any electrical charges. This makes it less likely to react with sulfate ions and more resistant to sulfate attack. The presence of PP fibers acts as a physical barrier and improves the overall durability of the concrete, leading to reduced sulfate attack.

- The SEM analysis confirms that the modified concrete with fly ash and PP fiber exhibits superior micro-structural characteristics, including reduced porosity and improved crack control. The R-PPF also play a role in reducing porosity by bridging gaps and limiting the formation and propagation of cracks. These findings support the conclusion that incorporating fly ash and PP fiber in the concrete mixture can potentially enhance the performance and durability of the material compared to the Control C25 Concrete.

In general, incorporating fly ash and recycled PP fiber in the concrete mixture offers several advantages, including improved workability, increased strength, enhanced durability, reduced water absorption, and a better sulfate attack resistance. These findings highlight the potential of utilizing fly ash and PP fiber as sustainable and effective modifications for enhancing the performance and longevity of concrete structures.

5.2 Recommendations

Based on the findings of this study, the following recommendations are suggested for further research and practical applications:

- Optimize the dosage of fly ash and R-PP fiber: Further investigation should be conducted to determine the optimal dosage of fly ash and PP fiber to achieve the desired balance between workability, early-age strength development, and long-term strength development.
- A well-controlled production of PP fibers: The production of R-PP fibers for concrete reinforcement involves considering a better aspect ratio and manufacturing process. A high aspect ratio is preferred, allowing for better bonding and load transfer between the fiber and the concrete matrix. The manufacturing process includes extrusion, stretching, and cutting to produce desired lengths and orientations fibers.
- Considering different types of supplementary cementitious materials (SCMs): In addition to fly ash, other supplementary cementitious materials such as silica fume or slag can be explored to evaluate their effects on the properties of the concrete mixture.
- Study the long-term durability performance: By considering the long-term effect of SCMs and long-term durability tests, such as chloride ion penetration resistance and carbonation resistance, should be conducted to assess the durability performance of the concrete incorporating fly ash and R-PP fiber.
- Evaluate the economic and environmental aspects: A comprehensive cost-benefit analysis and life cycle assessment should be conducted to evaluate the economic and environmental impacts of using fly ash and PP fiber in concrete production.
- Field application and monitoring: Field trials should be carried out to validate the laboratory findings and monitor the performance of the concrete in real-world conditions over an extended period.

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APPENDIX – A: PHYSICAL PROPERTIES OF CEMENT

The Normal consistency test for Ordinary Portland Cement (OPC) is conducted to determine the amount of water required to produce a cement paste of standard consistency. The test method is specified by ASTM C187. Here is a step-by-step procedure for conducting the normal consistency test for OPC using ASTM standards:

Step 1 Sample preparation: Obtain a representative sample of the OPC weighing 500 grams according to ASTM guidelines. Ensure that the sample is free from any lumps or foreign materials.

Step 2 Mixing: Gradually add water to the cement powder while continuously mixing using the standard consistency apparatus. Start with 22% of the weight of cement, which is 110 grams of water. Mix the cement and water for 3 minutes until a uniform paste is formed.

Step 3 Consistency determination: Continue adding water in increments of 1% and mixing until the paste reaches the desired consistency. After adding an additional 25 grams of water (5% of the weight of cement), we find that the paste has a smooth and plastic consistency.

Step 4 Mold filling: Fill the Vicat mold with cement paste, ensuring it is completely filled and leveled off.

Step 5 Initial Needle Placement: Lower the Vicat plunger with the initial needle attached to it,so that the needle gently touches the surface of the cement paste.

Step 6 Time recording: Start the timer and allow the cement paste to set undisturbed for 30 minutes.

Step 7 Needle penetration: At regular intervals of 5 minutes, lower the Vicat plunger with the second needle attached to it and gently penetrate the cement paste with the needle. Measure the penetration depth.

At 5 minutes,the penetration depth was 24 mm.

At 10 minutes,the penetration depth was 18 mm.

At 15 minutes,the penetration depth was 12 mm.

At 20 minutes,the penetration depth was 8 mm.

At 25 minutes,the penetration depth was 6 mm.

At 30 minutes,the penetration depth was 5 mm.

Step 8 Consistency calculation: Calculate the average penetration values of the two needles at each time interval. Based on the data, found the average penetration depth at 30 minutes is 5.5 mm, which falls within the specified range of 5-7 mm. Therefore, we conclude that the normal consistency of the OPC paste is achieved with 27 % (135 grams) of water.

APPENDIX – B: CHEMICAL COMPOSITION

The Complete silicate analysis report of Fly ash

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

Customer Name:- Abei Mequannet

Issue Date:-08/03/2023

Sample type :-Powder

Request No:- GLD/RQ/841/23

Sample Preparation: -200 Mesh

Report No:- GLD/RN/1508/23

Date Submitted:- 17/02/2023

Number of Sample:-One (01)

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H2O	LOI	Weight of Sample
Am-01	50.78	30.42	4.60	<0.01	0.28	0.22	1.08	<0.01	0.24	0.64	4.10	8.44	900.00 gm

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

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

APPENDIX – C: PHYSICAL PROPERTY TESTS FOR FINE AGGREGATES

Specific Gravity and Absorption Capacity

According to ASTM C 128, the bulk specific gravity of fine aggregates ranges between 2.6 to 2.8. Accordingly, the following result was found.

$\text{Weight of the sample, SSD} = 500\text{g}$

$\text{Weight of pyconometer} + \text{water} = 1590\text{g}$

$\text{Weight of pyconometer} + \text{water} + \text{sand} = 1902\text{g}$

Weight of oven dried sample on air = 495 g

$$\text{Bulk specific gravity (SSD)} = \frac{500}{(500 + 1590 - 1902)} = 2.66$$

$$\text{Apparent specific gravity} = \frac{495}{(495+1590-1902)} = 2.705$$

According to ASTM C 128 to test the increase in weight of aggregate due to water in the pore of the material so the water absorption of the material must be tested. Absorption is a measure of the total pore volume accessible to water. Its also useful for mix design moisture adjustment.

S=Weight of SSD=500 gm

A=Weight of oven dried sample on air=495 gm

Absorption%=S-A/A=(500-495)/495*100=1.01%

Silt Content

The ASTM standard for determining the silt content in fine aggregates is ASTM C117-17a. The procedure involves the following steps:

Step 1: Prepare a cylinder having a capacity of 1000 ml.

Step 2: Pour 300 ml of sand into the cylinder.

Step 3: Approximately fill 3/4 cylinder with water.

Step 4: Stir and shake the mixture of water and sample in Cylinder, ensuring that all particles are thoroughly wetted.

Step 5: Allow the mixture to settle for an hour to allow the silt to settle on the top layer of the sand.

Step 6: Carefully measure the volume of silt settled separately on top the sand and the volume of clean sand settled separately on the bottom.

Step 7: Calculate the silt content percentage by dividing the volume of silt to the volume of clean sand settled on the bottom.

Silt Content%=(V_1/V_2) x 100

Where V_1-Volume of silt layer

V_2-Volume of sand layer

Silt content=7.2/300=2.4 %

Moisture Content

The following data are the samples weight that are taken to the calculation.

Weight of the original sample (Os)=2000 gm

Weight of the oven dry sample (Ods)=1093.73 gm

Moisture content %= $\frac{Os - Ods}{Ods} = \frac{2000 - 1093.73}{1093.73}$ = 0.83%

Unit weight

Unit weight also known as bulk density and conducted according to ASTM C 29; the unit weight of the fine aggregates is between 1280 to 1920 kg/m which is helps to determine the weight of sand in a given volume of graded sand. There for the fine aggregate unit weight is calculated as follows.

B= Weight of sample+ container=8.35 kg

A= Weight of container=2.96 kg

V=Volume of container=0.0034 m^3

Unit weight=(B-A)/V= (8.35-2.96)/0.0034=1,585.29 Kg/m^3

2 . Physical Property Tests for Coarse Aggregates

1.1 Specific Gravity and Absorption Capacity

The range of specific gravity and absorption values for coarse aggregate as per ASTM C127/C127M are as follows:

Specific Gravity: Specific gravity of coarse aggregate ranges from 2.5 to 2.9.

Oven dry=998.88 gm

SSD in air=2517.2 gm

SSD in water=1567.31gm

Bulk ssd = SSD in air/(SSD in air - SSD in water)

Bulk ssd=2517.2/(2517.2-1567.31)=2.65

Absorption: For normal- weight aggregate, ranges from 0.5 % to 2.0 %.

For lightweight aggregate, range from 0.5% to 10.0 %

Absorption= SSD in air - Oven dry/Oven dry

Absorption=2517.2- 998.88/998.88=1.52 %

Moisture Content

The following data are the samples weight that are taken to the calculation.

Weight of the original sample (Os)=5000 gm

Weight of the oven dry sample (Ods)=493.73 gm

Moisture content % = $\frac{Os - Ods}{Ods} = \frac{5000 - 493.73}{493.73}$=1.27 %

Unit weight test

Unit weight also known as bulk density and conducted according to ASTM C29. It is the weight of aggregate in a given volume of graded aggregate. It is calculated as follows.

Weight of sample+ Container=6.97 kg

Weight of container =4.73 kg

Volume of container = 0.001375 m^3

Unit weight = $\frac{\text{(Weight of sample + container) - Weight of container}}{\text{Volume of container}}$

Unit weight=(6.97-4.73)/0.001375=1,585.29 Kg/m^3

The dry rodded unit weight of coarse aggregate is also determined using the ASTM C29/C29M standard test method. The process involves sample preparation, oven drying, rodding, weighing and calculation. That is;

Dry Rodded Unit Weight= $\frac{\text{Weight of compacted aggregate}}{\text{Volume of measure container}} = \frac{2.207}{0.001375} =$ 1605 kg/m^3

APPENDIX – D: THE PROCESS USED IN PP RECYCLING

Here is a general outline of the process used in this study paper:

Step 1 Collection and Sorting: The first step is was to collect and sort the waste polypropylene materials. These can include used plastic products, such as packaging materials, containers, or textiles, that are made of polypropylene.

Figure D-1 Post-consumer product of polypropylene plastic waste packaging materials

Step 2 Cleaning and Shredding: The collected polypropylene waste is thoroughly cleaned to remove any contaminants or impurities. The cleaned material is then shredded into smaller pieces to facilitate further processing.

Step 3 Melting and Extrusion: The shredded polypropylene is melted using high temperatures in an extruder. The molten polypropylene is then forced through a spinneret, a device with small holes, to form continuous filaments. These filaments are then solidified by cooling, typically through a water bath or air cooling.

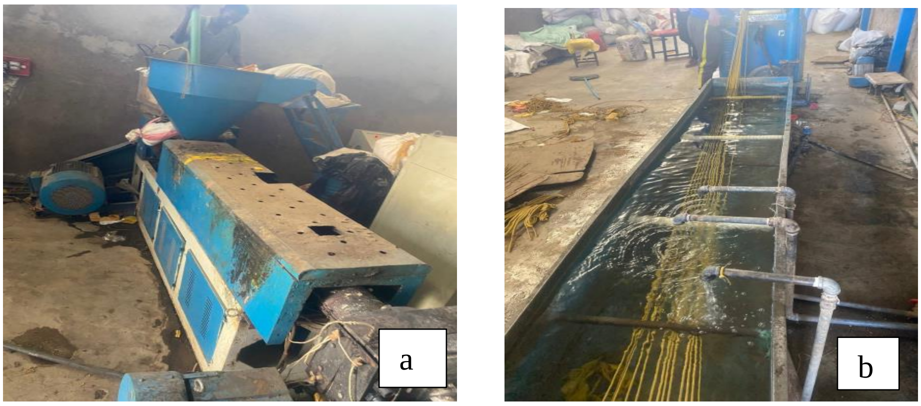

Figure D-2 Melting and Extrusion a) Melting b) Extrusion and solidification through water

Step 4 Stretching and Cutting: The solidified filaments are stretched to align the polymer chains and improve the mechanical properties of the fiber. This stretching process, known as orientation, enhances the tensile strength and durability of the recycled PP fiber. After stretching, the fiber is cut into desired lengths.

Figure D-3 Stretching and cutting polypropylene plastic

APPENDIX – E: MIX DESIGN

The Mix design procedure followed by this experimental procedure is as follows:

Required average Compressive Strength when data are not available to establish standard deviation presented below.

Specified compressive strength, f’c, and required average compressive strength, f’cr,

in MPa according to ACI 318.

- For Less than 21 *f’c +7.0*
- For 21-35 *f’c +8*
- Over 35 1.1 *f’c+5.0*

For characteristics strength of 25 MPa, the required average strength at 28 day is can be calculated by the following equation.

$f'cr = f'c+8$ for $f'c$ is between 21 and 35

$f'cr$ = f'c+8.5=25+8=33 mpa

Step 1 Slump selection

From table 6.3.1 of ACI-2111-91, assume for a better workability that is:

a max slump=75 mm and min slump=25 mm.

Table E-1 Recommended slumps for various types of construction

Types of construction	Maximum Slump(mm)	Minimum Slump(mm)
Reinforced foundation walls and footing	75	25
Plain footing caissons and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavement and slabs	75	25
Mass concrete	75	25

Step 2 Maximum size of aggregate selection

19 mm maximum nominal aggregate size was selected.

Step 3 Estimation of water content

From ACI 211.1-91 table 6.3.3, for a slump of 25-75 mm and the maximum size of aggregate of 19 mm, let the water requirement is around 197.5 kg/m^3 (by interpolation) with a corresponding 2% air entrapped in non-air entrained concrete.

Table E-2 Approximate mixing water and air content requirement

NON-AIR-ENTRAINED CONCRETE								
Slump (mm)	**9.5 mm**	**12.5 mm**	**19 mm**	**25 mm**	**37.5 mm**	**50mm**	**75 mm**	**150 mm**
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
More than 175	-	-	-	-	-	-	-	-
Approximate amount of entrapped air in non-air-entrained concrete (%)								
Slump (mm)	**9.5 mm**	**12.5 mm**	**19 mm**	**25 mm**	**37.5 mm**	**50 mm**	**75 mm**	**150 mm**
All	3	2.5	2	1.5	1	0.5	0.3	0.2

Step 3 Selection of water-cementitious ratio

From ACI 211.1-91 table 9.3, the water-cementitious ratio concrete with compressive strength is given.

Table E-3 Relationship between water cement or water-cementitious materials ratio and compressive strength of concrete.

Compressive strength at 28 days (MPa)	Water-cement ratio by weight (Non-air-entrained concrete)
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69
15	0.79

But from the Slump test experiment an average workable water to cementitious ratio of 0.52 was found.

According to ACI 211.1-91 when natural pozzolans, fly ash, GGBF slag, and silica fume, commonly called as pozzolanic materials, are used in concrete, a water-to-cement plus pozzolanic materials ratio (or water-to-cement plus other cementitious materials ratio) by weight must be considered in place of the traditional water-cement ratio(w/c)by weight. There for using equivalent weight of pozzolanic materials approach, the weight equivalency(w/c) and the total weight of pozzolanic materials remains the same.

$$\frac{w}{c} = \frac{w}{c+p} \qquad \text{...} \quad \text{(Eq. E-1)}$$

Where

W=weight of water

C=weight of cement

P=weight of pozzolanic material (fly ash)

Step 4 Calculation of cement content

For slump of 25-75 mm

Water content=197.5 Kg/m^3

Water/cement=0.52

Cement content=Water content/(w/c) =197.5/0.52=379.81

Step 5 Estimation of coarse aggregate content

From table 6.3.6 of ACI 211.1-91, for maximum size of aggregate=19 mm and fineness modules for sand=2.69,the volume of oven dry rodded coarse aggregate per unit volume of concrete is around 0.63 m^3.

Table E-4 Volume of coarse aggregate per unit volume of concrete

Nominal maximum size of aggregate (mm)	2.4	2.6	2.8	3
9.5	0.5	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.6
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.8	0.78	0.76
150	0.87	0.85	0.83	0.81

The required dry mass of C. A=Volume of C.A per unit volume*Dry Rodded Unit Weight

$$=0.63*1605=1011.15\ kg/m^3$$

Step 6 Estimation of fine aggregate content

All ingredients of the concrete have been estimated except the fine aggregate because it has a specified dimension which can be measured. Its quantity is determined by difference. The weight method and absolute volume method. If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients. Therefore, in this paper the weight method preferred.

Content of fine aggregate (F.A)=unit wt. Of concrete-(C.A+cement+water)

First let's estimate the unit weight of fresh concrete.

From ACI 211.1-91 table 6.3.7.1 the unit weight of fresh concrete corresponding to max Aggregate.

Table E-5 First estimate of weight of fresh concrete

Nominal maximum size of aggregate (mm)	Non-air entrained concrete (Kg/m^3)
9.5	2280
12.5	2310
19	2345
25	2380
37.5	2410
50	2445
75	2490
150	2530

Size of 19 mm and non-air entrained is 2345 kg/m^3

Mass of Water (net mixing) =197.5 kg/m^3

Mass of Cement=379.81 kg/m^3

Mass of Coarse aggregate (C.A) =1011.15 kg/m^3

Content of fine aggregate (F.A) =2345 kg/m^3-(1011.15+379.81+197.5)kg/m^3

$$=2345-1588.46=756.54\ kg/m^3$$

Final weight of ingredients before adjustment

weight of ingredients before arrangement

Concrete ingredients Weight of ingredients before arrangement

Water 197.5 Kg/m^3

Cement 379.81 Kg/m^3

Coarse aggregate 1011.15 Kg/m^3

Fine aggregate 756.54 Kg/m^3

Step 7 Adjustment for ingredients due to water absorption capacity and moisture content

Water adjustment in concrete is necessary to compensate for the water absorbed by the aggregate. When aggregates are mixed with concrete, they can absorb a certain amount of water, which affects the overall water content and consistency of the mixture. To maintain the desired water-cement ratio and achieve the desired workability, it is important to adjust the water content accordingly.

If the moisture content is higher than the capacity for absorption, the absorbed water does not mix with the water and must be removed. But, if absorption capacity is greater than moisture content of aggregate, we need to add water up to its moisture capacity.

The adjustment is made by considering the absorption capacity and moisture content. The formula typically used is:

$$\text{Adjusted Quantity}=\frac{\text{Design Quantity}}{(1+(\text{Absorption Capacity}/100))*(1+(\text{Moisture Content}/100))} \quad \text{(Eq. E-2)}$$

Coarse aggregate adjustment (Absorption capacity 1.52% and has moisture content of 1.27%), so that adjusted C.A content:

$$=\frac{1011.15}{(1+(1.52/100))\ x\ (1+(1.27/100))}$$

$=983.51\ kg/m^3$

Fine aggregate adjustment (Absorption capacity 1.01% and has moisture content of 0.83%), so that adjusted F.A content:

$$=\frac{756.54}{(1+(1.01/100))x(1+(0.83/100))}$$

$=742.79\ kg/m^3$

Water adjustment (additional water is required for the amount absorbed by course and fine aggregate)

First,Calculate the amount of water absorbed by the C.A:

Water absorbed by C.A=(Absorption capacity of C.A*Weight of C.A)/100

$=(1.52\%*1011.15\ kg/m^3)/100=15.4\ kg/m^3$

Secondly,Calculate the amount of water absorbed by F.A:

Water absorbed by F.A=(Absorption capacity of F.A*Weight of F.A)/100

$=(1.01\%*756.54\ kg/m^3)/100=7.64\ kg/m^3$

Third,Calculate the total amount of water absorbed by the aggregates:

Total water absorbed by aggregates=Water absorbed by C.A+ Water absorbed by F.A

$=15.4\ kg/m^3+7.64\ kg/m^3=23.04\ kg/m^3$

Calculate the adjusted water amount:

Adjusted water amount=Total water absorbed by aggregates-Moisture content of C.A-Moisture content of F.A

$=23.04-(1.27/100*1011.15)-(0.83/100*756.54)=22.88-12.84-6.28=3.76\ kg/m^3$

New water amount=197.5+3.76=201.26 kg/m^3

Final weight of ingredients after adjustment

The proportion of ingredients for the 10 types of trial mix,60 casts for each strength test and 30 cubes for durability were made and calculated below but before we proceed with the required quantity of each ingredient lets calculate the total required volume of fresh concrete:

Trial Mix volume

=3*10*2*(0.15*0.15*0.15)+2*10*(0.07*0.07*0.07)+3*10*2*(3.14*0.005625*0.3)
+3*10*2*(0.5*0.1*0.1)

=60*0.003375+20*0.000343+60*0.005299+60*0.005

=0.2025+0.00686+0.31794+0.3

=0.8273

Mix volume=0.8273 m^3+15%for shrinkage and wastage

Mix volume=0.8273 m^3+(0.8273 m^3*0.15)=0.9514 m^3

Concrete ingredients Weight of ingredients after adjustment

Water 201.26 Kg/m^3 but For 0.9514 m3 191.48 kg

Cement 379.81 Kg/m^3 but For 0.9514 m3 361.35 kg

Coarse aggregate 983.51 Kg/m^3 but For 0.9514 m3 935.71 kg

Fine aggregate 742.79 Kg/m^3 but For 0.9514 m3 706.69 kg

APPENDIX – F: AVERAGE COMPRESSIVE STRENGTH, SPLIT TENSILE STRENGTH, AND FLEXURAL STRENGTH TEST RESULTS FOR THE 7TH AND 28TH DAYS

			Average compressive strength test result for 7th and 28th day (mpa)									
			Control FA0-PP 0	T FA0-PP 0.5	T FA0-PP1	T FA0-PP1.5	T FA10 -PP 0.5	T FA10-PP1	T FA10-PP1.5	T FA20-PP0.5	T FA20-PP1	T FA20-PP1.5
7 day test	Sample 1	Weight (kg)	8.18	7.92	8.04	7.97	7.59	7.67	7.63	7.90	8.05	8.01
		Stress	18.19	18.78	20.12	19.56	18.51	19.86	19.54	18.20	19.55	19.30
	Sample 2	Weight (kg)	8.17	8.05	8.04	8.04	7.81	7.73	7.74	8.07	8.08	8.04
		Stress	18.27	18.96	21.99	20.59	19.30	21.55	20.22	18.50	20.95	19.80
	Sample 3	Weight (kg)	8.17	8.00	8.04	8.05	7.55	7.70	7.67	8.09	8.08	8.07
		Stress	18.20	18.90	22.87	21.53	17.75	19.94	19.19	18.20	21.96	19.31
	Mean stress		18.22	18.88	21.66	20.56	18.52	20.45	19.65	18.30	20.82	19.47
28 day test	Sample 1	Weight (kg)	8.26	8.00	8.12	8.05	7.67	7.75	7.71	7.98	8.13	8.09
		Stress	29.80	29.08	30.25	31.22	32.05	39.95	36.56	32.59	34.98	32.67
	Sample 2	Weight (kg)	8.26	8.13	8.12	8.12	7.89	7.81	7.82	8.15	8.16	8.12
		Stress	30.10	31.30	30.95	31.95	33.56	40.89	38.45	33.45	35.89	32.88
	Sample 3	Weight (kg)	8.25	8.08	8.12	8.13	7.63	7.78	7.75	8.17	8.16	8.15
		Stress	27.43	29.59	31.32	32.50	32.91	41.41	37.76	34.49	35.66	32.70
	Mean stress		29.11	29.99	30.84	31.89	32.84	40.75	37.59	33.51	35.51	32.75

Figure E-1 Average compressive test results for the 7th and 28th day

			Average tensile strength test result for 7th and 28th day (mpa)									
			Control FA0-PP 0	T FA0-PP 0.5	T FA0-PP1	T FA0-PP1.5	T FA10 -PP 0.5	T FA10-PP1	T FA10-PP1.5	T FA20-PP0.5	T FA20-PP1	T FA20-PP1.5
7 day test	Sample 1	Weight (kg)	12.23	12.64	12.62	12.76	11.77	12.03	12.07	11.37	11.47	11.43
		Stress	1.82	2.00	2.29	2.45	2.69	3.34	3.05	2.55	3.33	2.99
	Sample 2	Weight (kg)	11.98	12.76	12.82	12.74	11.67	12.18	11.93	11.46	11.40	11.39
		Stress	1.79	2.08	2.41	2.35	2.92	3.78	3.25	2.65	3.45	3.15
	Sample 3	Weight (kg)	12.77	12.82	12.72	12.69	11.63	12.18	12.12	11.36	11.39	11.39
		Stress	1.82	2.04	2.47	2.52	2.79	3.38	3.30	2.45	2.97	3.01
	Mean stress		1.81	2.04	2.39	2.44	2.8	3.5	3.2	2.55	3.25	3.05
28 day test	Sample 1	Weight (kg)	12.35	12.77	12.75	12.89	11.89	12.15	12.19	11.48	11.59	11.55
		Stress	3.05	3.12	3.45	3.45	3.89	4.65	3.99	3.78	4.31	4.05
	Sample 2	Weight (kg)	12.10	12.89	12.95	12.87	11.79	12.30	12.05	11.58	11.52	11.50
		Stress	3.19	3.45	3.35	3.55	3.90	5.10	4.12	3.69	4.51	4.18
	Sample 3	Weight (kg)	12.90	12.95	12.85	12.82	11.75	12.30	12.24	11.47	11.51	11.51
		Stress	3.09	3.33	3.40	3.50	4.06	4.50	3.89	3.51	4.41	4.19
	Mean stress		3.11	3.3	3.4	3.5	3.95	4.75	4	3.66	4.41	4.14

Figure E-2 Average split tensile strength results for the 7th and 28th day

			Average Flexural test result for 7th and 28th day (mpa)									
			Control FA0-PP 0	T FA0-PP 0.5	T FA0-PP1	T FA0-PP1.5	T FA10 -PP 0.5	T FA10-PP1	T FA10-PP1.5	T FA20-PP0.5	T FA20-PP1	T FA20-PP1.5
7 day test	Sample 1	Weight (kg)	11.67	12.55	12.52	12.76	12.23	12.27	12.07	11.97	12.11	11.43
		Stress	3.01	3.22	3.31	3.12	3.55	3.68	3.36	2.79	3.33	2.79
	Sample 2	Weight (kg)	11.77	12.76	12.77	12.70	12.27	12.18	11.93	12.46	12.24	11.53
		Stress	3.15	3.34	3.32	3.16	3.69	3.77	3.49	2.95	3.45	2.65
	Sample 3	Weight (kg)	11.10	12.91	12.87	12.73	12.54	12.62	11.91	12.07	11.56	11.25
		Stress	3.23	3.16	3.51	3.29	3.59	3.95	3.41	2.93	3.12	2.78
	Mean stress		3.13	3.24	3.38	3.19	3.61	3.8	3.42	2.89	3.3	2.74
28 day test	Sample 1	Weight (kg)	11.79	12.68	12.65	12.89	12.35	12.39	12.19	12.09	12.23	11.55
		Stress	3.79	4.05	4.25	3.88	5.81	6.59	5.50	4.82	4.88	4.66
	Sample 2	Weight (kg)	11.89	12.89	12.90	12.83	12.39	12.30	12.05	12.59	12.36	11.65
		Stress	4.10	4.20	4.41	3.99	5.55	7.12	5.40	4.78	4.99	4.45
	Sample 3	Weight (kg)	11.21	13.04	13.00	12.86	12.67	12.75	12.03	12.19	11.68	11.36
		Stress	4.14	4.29	4.27	4.16	5.83	7.26	5.66	4.89	5.01	4.51
	Mean stress		4.01	4.18	4.31	4.01	5.73	6.99	5.52	4.83	4.96	4.54

Figure E-2 Average flexural strength results for the 7th and 28th day

APPENDIX – G: WATER ABSORPTION TEST

The test was conducted to determine the water absorption characteristics of a concrete cube with a side length of 70 mm, following step by step guidelines outlined in ASTM C642.

Step 1: The cube was thoroughly dried by placing it in an oven at approximately 100°C for 24 hours. This ensured the removal of any surface moisture before the test.

Step 2: After drying, the cube was allowed to cool to room temperature in a desiccator to prevent moisture absorption from the surrounding environment.

Step 3: The initial weight of the cube was measured using a precision balance and recorded.

Step 4: The cube was then submerged in distilled water for a specified immersion period of 24 hours.

Step 5: After the immersion period, the cube was removed from the water, and any visible surface moisture was gently wiped off using a damp cloth.

Step 6: The final weight of the cube was measured using the same precision balance and recorded.

Step 7: Calculate water absorption percentage using equation 3.4.

APPENDIX – H: SULFATE ATTACK TEST

In the sulfate attack test using mass loss, the following steps are typically followed:

Step 1: Prepare concrete cubes according to the desired mix design, which typically includes the use of Portland cement, aggregates, water, and any other additives or admixtures. The dimensions of the cubes were made 150 mm per side.

Step 2: Cure the concrete cubes in a standard curing condition, water immersion curing, for a 28 days period to allow for proper hydration and strength development.

Step 3: Measure the initial mass of each cube before exposing them to sulfate solution.

Step 4: Immerse the cured concrete cubes in 5% sulfate chemical solutions (Sodium sulfate solution). The cubes are fully submerged in the solution, ensuring complete exposure to the sulfate ions.

Step 5: The cubes were kept in the sulfate solution for 28 days.

Step 6: At the end of the test period, the cubes were removed from the sulfate solution and cleaned to remove any residual sulfate solution. Then, determine the final mass of each cube after the exposure period.

Step 7: Calculate the mass loss of each cube by comparing the initial and final masses. The mass loss is typically expressed as a percentage of the initial mass and calculated with equation 3.5.

Step 8: Evaluate the mass loss results according to the acceptance criteria specified in the project specifications or relevant standards.