STRENGTH PROPERTIES AND TEMPERATURE OF C55/67 CONCRETE PREPARED WITH VARIOUS TYPES OF CEMENT

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"STRENGTH PROPERTIES AND TEMPERATURE OF C55/67 CONCRETE PREPARED WITH VARIOUS TYPES OF CEMENT"** was prepared by **CHIN KAH HENG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours at Universiti Tunku Abdul Rahman.

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ABSTRACT

The evolution of concrete technology has introduced numerous cement types, each with unique compositions affecting concrete properties, making the selection of the appropriate cement critical for achieving desired results, especially in civil engineering applications. The research addresses the feasibility of substituting different cements without compromising the desired strength, particularly in ready-mix concrete scenarios where material shortages may occur. This study explores the influence of various cement types on the properties of C55/67 concrete, with specific aims to achieve the design strength at 28 days, and to examine the fresh and mechanical properties, as well as the temperature characteristics of the concrete. It also considers concrete mix design methodologies tailored to specific cement types to ensure optimal performance and quality in diverse environmental conditions, with a particular focus on enhancing concrete quality and reliability in water-retaining structures where crack prevention is paramount. The study's trial mix, using control mix of OPC 42.5N, achieved the desired slump value (60-180 mm) and a compressive strength of 67 MPa at 28 days, making it the basis for the actual mix application. In actual mix, test results indicated that OPC 42.5N exhibited the highest workability, followed by OPC 52.5N, PLC 32.5N, and PFA 32.5N, in that order. This sequence was consistent for the hardened density of the concrete. PFA 32.5N had the shortest initial setting time. For compressive strength, OPC 42.5N demonstrated the highest strength, with OPC 52.5N following, and PFA 32.5N and PLC 32.5N trailing at both 7 and 28 days. By 56 days, OPC 52.5N showed a slightly higher compressive strength than OPC 42.5N, while PLC 32.5N and PFA 32.5N remained lower than those of concrete prepared with OPC cements. Temperature tests revealed that PLC 32.5N reached its peak temperature the quickest, followed by OPC 52.5N, PFA 32.5N, and OPC 42.5N. However, OPC 52.5N reached a significantly higher peak temperature than the others, followed by PLC 32.5N, OPC 42.5N, and PFA 32.5N. Overall, OPC 42.5N showed the best performance across workability, strength, and temperature tests, making it the preferred choice for ensuring concrete quality and reliability in various environmental conditions.

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LIST OF SYMBOLS / ABBREVIATIONS

°C	Degree Celsius
Ac	Cross-sectional Area, m^2
F	Maximum Load, N
fc	Compressive Strength, MPa
kg	Kilogram
m	Metre
mm	Millimetre
psi	Pound-Force per Square Inch
SG	Specific Gravity
μm	Micrometre

Al2O3	Alumina
AS_3	Sulphoaluminate
C_2S	Dicalcium Silicate/ Belite
C_3A	Tricalcium Aluminate/ Celite
C_3S	Tricalcium Silicate/ Alite
C_4AF	Tetracalcium Aluminoferrite/ Brownmillerite
$Ca(OH)_2$	Portlandite
CaO	Calcium Oxide/ Lime
CO_2	Carbon Dioxide
CSH	Calcium Silicate Hydrate
Fe2O3	Iron (III) Oxide/ Ferric Oxide/ Hematite
GGBS	Ground Granulated Blast-Furnace Slag
K2O	Potassium Oxide
MgO	Magnesium Oxide/ Magnesia/ Periclase
Mno	Manganese Oxide
OPC 42.5N	Ordinary Portland Cement with Grade 42.5N
OPC 52.5N	Ordinary Portland Cement with Grade 52.5N
OPC	Ordinary Portland Cement
P2O5	Phosphorus Pentoxide
PCC	Portland Composite Cement

PFA	Pulverised Fly Ash
PFA 32.5N	Pulverised Fly Ash Cement with Grade 32.5N
PLC 32.5N	Portland Limestone Cement with Grade 32.5N
SCM	Supplementary Cementitious Materials
SiO2	Silicon Dioxide/ Silica
SO3	Sulphur Trioxide
SP	Superplasticiser
SSD	Saturated Surface Dry
Tio2	Titanium Dioxide
XRD	X-ray Diffraction Analysis
XRF	X-ray Fluorescence

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Concrete, the most common material in the construction industry nowadays, is widely used in building structures. In fact, people began using concrete for construction centuries ago, and it remains the primary choice for construction today. Due to the properties of concrete such as high compressive strength, high durability, easy to shape and high fire resistance, it had survived from the long history of human civilisation and remains the main material in construction industry today. Not only that, the availability of the raw materials for concrete manufacturing in the Earth and the cost effectiveness of using concrete as the main material are also the main reason why it is preferable in the construction industry.

There are few types of concrete which include lightweight concrete, normal weight concrete and heavyweight concrete depend on the density. Besides, concrete can also be categorized according to its strength such as normal strength, high strength and ultra-high strength concrete. A normal concrete is composed of cement, coarse aggregate, fine aggregate and water in proper ratio which depends on the usage and design targeted properties to be achieved. When cement is mixed with the water, a chemical reaction which is the hydration process will occur and form a hardened concrete. In concrete mix design, water to cement ratio is one of the most significant factors which will directly contribute to the characteristics of concrete such as workability and strength. Hence, it is important to get the correct mix proportions of concrete in order to achieve the desired characteristics.

In general, cement, fine aggregate, coarse aggregate, and water are the materials used in a concrete mix. However, some admixtures such as superplasticizer, accelerating admixture, air-entraining admixture, etc., may also be used in specific applications to achieve specific properties in fresh or hardened concrete. In addition, pozzolanic materials such as ground granulated blast furnace slag, fly ash, palm oil fuel ash, rice husk ash, etc., can also be added to concrete mix designs to replace a certain amount of cement and achieve different mix proportions compared to normal concrete. According to ASTM C150, there are 5 main types of cement depends on the ingredient (ASTM International, 2012). In general, Type I and Type II cement is commonly been used in normal concrete mix where Type I cement is made up of fully Ordinary Portland Cement and Type II is composite cement that contain Portland cement with the pozzolans.

1.2 Importance of the Study

Throughout the development of concrete technology, many types and brands of cement have been developed and introduced to the market. Due to the different ratios and ingredients used in different types of cement, the characteristics and performance of the concrete produced using the cement will certainly vary. The properties of concrete such as density, workability, durability, compressive strength, and concrete temperature will vary depending on the type of cement used. Therefore, it is important to study the relationship between the type of cement and the properties of concrete, as well as the reasons behind the differences in results produced by different types of cement.

Studying the different properties of concrete produced by various types of cement allows for the determination of the appropriate application of the cement in structures designed with specific concrete properties. The designed specific characteristic of the cement can be achieved by using the appropriate type of cement with the proper mix proportion of other material. Hence, the properties of concrete by various type of cement have to be studied in order to apply the proper material to the civil engineering application with designed purposes and result in a quality product. For example, for mass concreting, it is necessary to control the temperature of concrete to avoid cracking in hardened concrete. In this case, engineers are required to know the properties of each type of cement and choose the correct cement to meet the desired design. Therefore, it is important to study the behaviour of each type of cement in Malaysia.

1.3 Problem Statement

It has been found that Nigeria has conducted the most research on the properties of concrete using different brands of cement. According to Yola, et al. (2021), Arimanwa, et al. (2016) and Anejo, et al. (2014), detailed comparative studies on properties of concrete from different brands of cement in Nigeria were conducted. Additionally, according to Dahiru, et al. (2019), the research on the properties of concrete at elevated temperatures by various brands Ordinary Portland Cement (OPC) in Nigeria was studied. Besides, the study of effect of calcium chloride on the properties of concrete from different brands of cement in Nigeria was carried out by Odeyemi, et al. (2015). Other than Nigeria, the research has been also done in other countries. According to Mohammed (2007), the quality of different cement brands in Bangladesh was studied in detail. Moreover, the study on behaviour of concrete with various brands of cement in Pakistan had been done by Soltani, et al. (2019). In India, the comparative study on concrete strength by various brands of cement was done by Bhamere (2016). Although similar research was done by many researchers in different countries, there was no such study carried out in Malaysia. Hence, the comparative behaviours of various type of cement in Malaysia are still remain unknown.

Nowadays, there are various types of cement that can be found around the world. In Malaysia there are some cement brands available in the market such as YTL Cement, CIMA, Tasek and Hume cement, and each brand of cement offers different types of cement. Each type of cement will have different properties, so it is necessary to understand the behaviour of the cement to ensure that the appropriate type is used in the design to achieve the desired characteristics. On a construction site, the ready-mix concrete is usually used in constructing the concrete structure due to its cost effectiveness and it can be delivered in large amount each time to the site. However, in the event that a ready-mix concrete plant faces a shortage of a particular type of cement as a raw material, the question arises whether it can substitute this cement with another type possessing the same water/cement ratio while still achieving the desired compressive strength. Moreover, in the context of concrete mix design, particularly as outlined in the 2nd edition of the Design of Normal Concrete Mixes (Teychenné, et al., 1988), the focus appears to be primarily on the use of 42.5 and 52.5 class cements for both normal and pulverized fuel ash (PFA) cement. The query arises as to whether the same design methodology can be applied seamlessly to other types of cement or if adjustments are necessary for these alternative cement types and achieve the desired concrete strength. Hence, which type of cement is able meet the desired properties with same mixing methodology is required to be studied.

On top of that, during the concrete casting process, several variables, including ambient temperature, concrete temperature, wind speed, and humidity, can contribute to issues like bleeding and plastic shrinkage cracks. While factors such as ambient temperature, wind speed, and humidity are within our control and can be managed by selecting the optimal casting time to meet ideal conditions, concrete temperature remains a critical parameter that is not easily manipulated. This problem is more significant in water retaining structures, as cracking in concrete can lead to water leakage issues. Since heat is liberated during the hydration process of concrete with the addition of surrounding temperature, after the concrete dries, it will cool down, and thermal changes can cause cracks to develop inside the concrete. Therefore, to ensure the quality of the concrete, it becomes essential to conduct a thorough study of the temperature characteristics of concrete prepared using various types of cement. Hence, this research needs to be conducted on which type of cement yields the best performance in terms of maintaining the desired concrete temperature, ultimately enhancing the overall quality of the concrete.

1.4 Aim and Objectives

This study aims to investigate the strength properties and temperature of C55/67 concrete prepared with various types of cement. To achieve the aim of study, the objectives are listed as follows:

1. To achieve the design strength of C55/67 concrete at 28-day prepared with various types of cement.
2. To study the fresh and mechanical properties of C55/67 concrete prepared with various types of cement.
3. To study the concrete temperature of C55/67 concrete prepared with various types of cement.

1.5 Scope and Limitation of the Study

This research study mainly focuses on the strength properties and the temperature of concrete prepared with various types of cement. Five materials will be used in the concrete mix: cement, fine aggregate, coarse aggregate, water, and MasterGlenium ACE 8538 superplasticizer. Other admixtures, such as mineral admixtures, will not be added.

In this study, the designed concrete strength is set to be 28-day compressive cube strength of 67Mpa, therefore the mix proportion of the concrete have to be designed properly. The water/cement ratio was fixed to 0.26. Fresh properties of concrete, including density, workability, initial setting time, and temperature, will be assessed. The following test will encompass a comprehensive range of assessments to ensure the quality and performance of the concrete. These tests include evaluating the concrete's temperature to monitor the heat of hydration liberated, conducting a specific gravity test to determine the relative density of cement, sieve analysis for cement to assess the fineness of cement, assessing workability through tests such as the slump test, Vebe test and compacting factor test, measuring initial setting time to gauge the cement's curing properties, and conducting a fresh density test. Sieve analysis will be carried out to assess the distribution and fineness modulus of fine and coarse aggregate. The cement used in these assessments will be sourced from the following brands: Tasek brand, Orang Kuat brand, Castle Brand and Phoenix which are OPC 42.5N, OPC 52.5N and PLC 32.5N and PFA 32.5N respectively. Besides, there will be test to be carried out for the concrete strength test which is the compressive cube and cylinder strength test. Hence, the concrete will be cast in dimensions of 150 mm × 150 mm × 150 mm for cubes and 200 mm in diameter and 100 mm in height for cylinders. Concrete strength will be tested at 7, 28, and 56 days to observe the properties, especially for those using composite cement. The concrete will be cure in water before testing. All the test procedure will follow the BS and ASTM standard.

1.6 Contribution of Study

This study yields numerous benefits for the construction industry. By investigating how different types of cement influence C55/67 concrete strength, this study can provide crucial insights for optimizing concrete mixes. This optimization may lead to cost savings or enhanced performance in concrete properties, while ensuring the desired strength class of C55/67 is achieved. Furthermore, this research can promote sustainable construction practices by identifying alternative cement varieties with reduced environmental impacts yet still capable of delivering comparable strength. Ultimately, the research outcomes can inform the refinement of building regulations and standards, ensuring that structures are constructed using concrete that meets the necessary strength criteria. In addition, the effect of temperature on the strength of concrete is crucial for ensuring the long-term durability and performance of structures. By studying the concrete temperature during the hydration process, it can help predict the durability of structures, especially for crack-sensitive structures such as water-retaining structures. Additionally, this research can provide valuable input to cement manufacturers, aiding in the development of new cement types with enhanced performance attributes or tailored functionalities for specific applications.

1.7 Outline of the Report

This report is made up of six chapters, which are the introduction, literature review, methodology, result of trial mixes, result and discussion and conclusion and recommendations. The general introduction, importance of study, problem statement, aim and objectives, scope and limitation of study, and contribution of study are included in chapter 1. Lastly, the outline of report is shown in the end of chapter 1.

For chapter 2, the literature review on the types of cement, composition of cement, and properties of concrete is discussed. Moreover, the properties of raw materials for concrete and a literature review of previous research are also discussed.

Chapter 3 covers the methodology and work plan of this study. This chapter provides a detailed elaboration of the material preparation, mixing, casting, and testing procedures.

In chapter 4, the result of trial mix is discussed. The mix proportion design of concrete and corresponding results of workability and strength are the focus of this chapter. Finally, the optimum mix proportion design for the actual mix is determined in chapter 4.

Chapter 5 presents the results and discussion, comparing and discussing the results of the actual mix in terms of workability, density, initial setting time, compressive cube and cylinder strength, and concrete temperature. Furthermore, the oxide composition of cement paste from X-ray Diffraction Analysis (XRD) test is also discussed.

Last but not least, chapter 6 concludes the findings of this study in line with the study's objectives. In addition, recommendation for future work is provided.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, journal articles from other researchers were reviewed for information relevant to the objectives of this research. It initiates the discussion with a focus on the types of concrete, which include three types of cement. The advantages, disadvantages, and potential applications of different types of cement are explored. The chapter provides a comprehensive examination of the environmental impact of cement industry. Furthermore, it provides insights into the chemical composition of cement. The chapter also researches the properties of concrete based on experimental data from published journals and articles, including an examination of workability, density, concrete compressive strength, and concrete temperature.

2.2 Type of Cement

According to ASTM C150 (2012), there are 5 main types of cement in the market according to their raw material and composition as well as the manufacturing process. From Type I to Type V, the cements are classified in Ordinary Portland Cement (OPC), Portland Composite Cement (PCC), High Early-Strength Cement, Low Heat Cement and Sulphate-Resistant Cement respectively as shown in Table 2.1. For each main type of cement, the cement can be further separated into more type depends on the amount of additive used, and it can be divided into as much as 27 types of cement. Each type of cement has its own properties, so the different types of cement are to be designed for different application. In this sub-topic, the Type I, II and III cement will mainly be reviewed.

Table 2.1: General Properties of Different Types of Cement (ASTM International, 2012).

Types	General Properties
I	• Ordinary Portland Cement (OPC) • For general purpose
II	• Moderate heat of hydration • Moderate sulphate resistant
III	• High early-strength
IV	• Low heat of hydration
V	• High sulphate resistant

2.2.1 Type I Cement

Type I Cement is the OPC which is the most common type of cement used in the construction industry. It can be used for casting various types of concrete structure such as beam, slab, column, pavement, etc. OPC cement is often been used as the control mix when comparing to the other mix with admixture as the OPC is the standard cement that should be used as the reference mix. On the other hand, cement industry is one of the factors that causing the environment problem due to the carbon emission from the manufacturing of cement (Marques & Neves-Silva, 2015). Therefore, to reduce the carbon emission of cement manufacturing, the pozzolanic material such as fly ash can be used to replace certain proportion of cement (Vargas & Halog, 2015).

2.2.2 Type II Cement

Type II cement is the Portland Composite Cement (PCC) that have the properties of moderate sulphate resistant. Other than that, it can also reduce the heat of hydration compared to the Type I OPC cement. The lower heat of hydration can reduce the cracking in the concrete making it is suitable to be used in mass concrete construction (Xin, et al., 2022). Although Type II cement has lower early strength compared to the OPC, it can provide better long-term strength to the concrete. Type II cement is suitable to be used in application that required moderate sulphate resistant and lesser crack such as mass concrete structure, mass foundation casting and concrete dam structure.

2.2.3 Type III Cement

Type III cement is classified as high early-strength cement according to ASTM C150. It can develop higher early strength when compared with OPC. This is due to the higher tricalcium silicate (C3S) content and finely ground clinker in the cement (Jamal, 2017). Due to its high early-strength property, it is typically used in construction projects that require early loading and early formwork removal. Besides, it is also useful in low-temperature conditions, which lengthen the strength development time. Since the formwork and scaffolding can be removed early in the construction, Type III cement can speed up the project progress and hence lower the time and labour cost of a project. However, due to the high C3S content in Type III cement, it will release higher heat of hydration in the early strength developing process. This can lead to cracking in the concrete (Kipkemboi, et al., 2020). In addition, the cost of cement is also one of the disadvantages of Type III cement (Rafalko, et al., 2007).

2.3 Environmental Impact of Cement

Cement holds immense significance as a fundamental construction material essential for both housing and the development of infrastructure, and is important for the development of the economy (Mishra & Siddiqui, 2014). Cement is a fundamental material in creating concrete, essential for construction and civil engineering projects. On average, roughly one ton of concrete is manufactured per person annually worldwide. Figure 2.1 shows the amount of cement production by different countries from 1990 to 2050. Consequently, cement can be considered as one of the most significant man-made materials on our planet. (Devi, et al., 2018). Hence, its impact to the environment is significant.

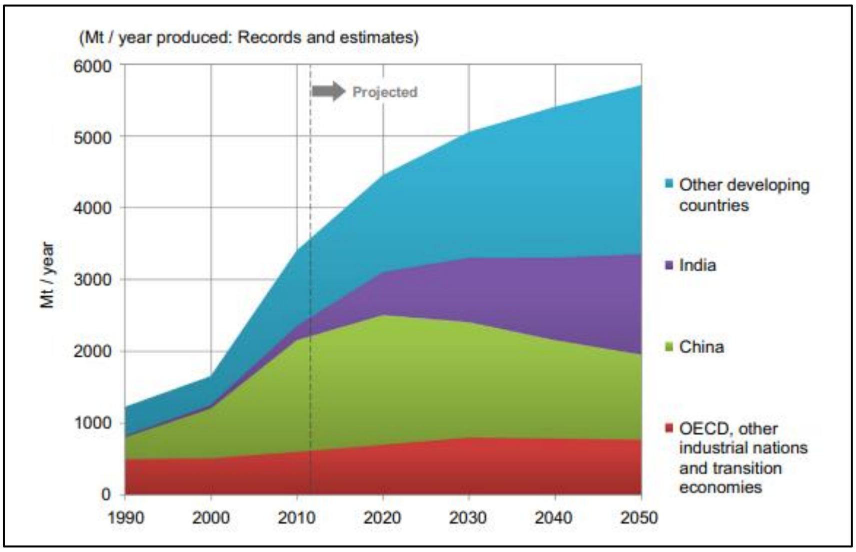

Figure 2.1: World Portland Cement Production from 1990-2050 (Imbabi, et al., 2012).

The cement industry demands substantial energy and holds a notable responsibility for climate change. Primary concerns related to environmental health and safety in cement production involve air emissions and energy consumption. The production of cement used vast quantities of unrenewable resources, such as raw materials and fossil fuels. It's estimated that approximately 5-6% of all human-induced carbon dioxide emissions, which contribute to greenhouse gases, stem from the manufacturing of cement (Johannes, 2012). Cement manufacturing involves mining and production steps. It takes about 1.7 tons of nonfuel raw materials to produce 1 ton of cement. Most of these materials, roughly 85%, are limestone or similar rocks, along with clay, shale, and other substances to achieve the right chemical composition. These materials are generally environmentally safe during mining. While individual quarries for cement materials may not be huge, the collective output of cement raw materials from thousands of plants worldwide is substantial, with nearly 3 billion tons needed annually for global cement production. The reserves of these materials are abundant from a geological perspective, though availability can vary at individual plants (Oss & Padovani, 2003).

The environmental impact of mining for cement raw materials is relatively limited compared to other mining sectors, with more substantial environmental concerns arising from the process of cement manufacturing itself, particularly in clinker production. This stage involves significant emissions of particulates and gases, notably carbon dioxide (CO_2), which has garnered international attention (Oss & Padovani, 2003). Numerous studies have provided estimates of carbon dioxide (CO_2) emissions per ton of cement production, highlighting the significant carbon footprint associated with concrete production, mainly attributed to the cement manufacturing process. Alternative cementitious materials like ground granulated blast-furnace slag (GGBS) and pulverised fly ash (PFA), both by-products of steel and coal industries respectively, are often employed to replace a portion of cement in concrete mixes. The use of water and admixtures in concrete can results in minimal CO_2 emissions (¸Sanal, 2017). To lower the cement content in concrete, limestone cement, GGBS cement, PFA cement, silica fume, etc. can be used (Imbabi, et al., 2012).

2.4 Composition of Cement

Cement is made up of 4 major chemical compound which include tricalcium aluminate, C_3A, dicalcium silicate, C_2S, tricalcium silicate C_3S, and tetracalcium aluminoferrite, C_4AF as shown in Table 2.2. Each of the chemical compound provide different properties to the concrete.

Table 2.2: Main Chemical Compound in Portland Cement (Neville, 2011).

Name of compound	*Oxide composition*	*Abbreviation*
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Dicalcium silicate	$2CaO.SiO_2$	C_2S
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

The strength of cement relies on its composition and how finely it is ground. C_3S is primarily responsible for early strength of hardening, while C_2S contributes to strength growth afterward. Alumina and iron compounds have a minimal impact on strength (Lea, n.d.). Thus, for the cement that require rapid hardening property usually will have higher content of C_3S.

Although by increasing the C_3S content in cement can provide rapid hardened properties to the concrete, it will release more heat during hydration process. Due to the heat liberated during cement hydration process, the temperature of the concrete structure will increase after casting, therefore, the large structure or mass concrete structure is recommended to used cement with low heat to avoid the thermal cracking. Among the four major chemical components in cement, C_3A will generates the highest heat of hydration, followed by C_3S, C_4AF, and C_2S.

C3A is a crucial component of cement, and its rapid reactivity with water during early hydration can significantly affect the mechanical properties and rheological performance of the cement mixture. If sulphates are not present to moderate this reaction, it can lead to the undesirable consequence of flash set, where the cement hardens too quickly (D. Marchon, 2016).

Cement and concrete can deteriorate due to chemical attack. Alumina in the cement is particularly susceptible to be attacked by sulphate where usually in soil with sulphate salts or seawater, whereas iron and the calcium silicates compound in the cement are more resistant to the sulphate attack. The release of calcium hydroxide during hydration is also vulnerable (Lea, n.d.). The Alumina will react with the sulphate and form sulphoaluminate (AS_3), this AS_3 will then react with the by-product of cement hydration which is portlandite ($Ca(OH)_2$) and form ettringite and monosulfate.

The percentage of main compound of cement can be calculated by using Bogue Equation 2.1.

$$
\begin{aligned}
C_3S &= 4.07(CaO) - 7.60(SiO_2) - 6.72(Al_2O_3) - 1.43(Fe_2O_3) - 2.85(SO_3) \\
C_2S &= 2.87(SiO_2) - 0.75(C_3S) \\
C_3A &= 2.65(Al_2O_3) - 1.69(Fe_2O_3) \\
C_4AF &= 3.04(Fe_2O_3)
\end{aligned}
\tag{2.1}
$$

Other than the four main compound, there are also some minor components in the cement such as MgO, TiO_2, Mn_2O_3, K_2O and Na_2O. Although they occupied relatively less amount in cement, they are also important to the behaviour of cement as those compounds can affect the rate of strength development of a concrete. Table 2.3 shows the common limit of composition of a Portland cement. Table 2.4 shows the typical chemical composition of Portland Cement.

Table 2.3: Common Limit of Composition of Portland Cement (Neville, 2011).

Oxide	*Content, per cent*
CaO	60–67
SiO_2	17–25
Al_2O_3	3–8
Fe_2O_3	0.5–6.0
MgO	0.5–4.0
Alkalis (as Na_2O)	0.3–1.2
SO_3	2.0–3.5

Table 2.4: Typical Chemical Composition of Portland Cement (Neville, 2011).

Chemical Composition (%)			Compound Composition Calculated by Bogue Equation	
CaO	63		C_3A	10.8
SiO_2	20		C_3S	54.1
Al_2O_3	6		C_2S	16.6
Fe_2O_3	3		C_4AF	9.1
MgO	1.5		Minor compound	-
SO_3	2			
K_2O Na_2O	1			
Others	1			
Loss on ignition	2			
Insoluble residue	0.5			

2.5 Standard Specification Label of Portland Cement

Cement typically comes labelled with its specifications, which serve as vital indicators of its properties. In accordance with BS EN 197-1:2000 (2000), various designations such as CEM I 52.5 N, CEM II B-V 42.5 N, etc. are used as examples. These specifications offer valuable insights into the characteristics and performance of the cement in question, providing essential information for construction and engineering applications. Table 2.5 shows the meaning specification label notation according to EN 197-1:2000 (2000). Table 2.6 shows the composition in family of common cement according to MS EN 197-1:2014 (2014).

Table 2.5: Summary of Specification Label Notation (EN 197-1:2000,2000).

Notation	Specification	
CEM	Cement	
I, II, III, IV, V	Type of cement	
32.5, 42.5, 52.5	Strength class of cement	
A	Proportion of the supplementary cementitious materials (SCM) between 6% and 20%	
B	Proportion of the SCM between 21% and 35%	
C	Proportion of the SCM between 36% and 55%	
K	Portland cement clinker	
S	Granulated blastfurnace slag	
P	Pozzolanic materials	Natural pozzolana
Q		Natural calcined pozzolana
V	Fly ashes	Siliceous fly ash
W		Calcareous fly ash
T	Burnt shale	
L	Limestone	< 0.2 % by mass
LL		< 0.5 % by mass
D	Silica fume	
N	Ordinary early strength	
R	Rapid setting, high early strength	
LH	Low heat	
SR	Sulphate resistant	

Table 2.6: Composition of Common Cement (MS EN 197-1:2014, 2014).

Main types	Notation of the 27 products (types of common cement)		Composition [percentage by mass [a]] — Main constituents: Clinker K	Blast-furnace slag S	Silica fume D [b]	Pozzolana natural P	Pozzolana natural calcined Q	Fly ash siliceous V	Fly ash calcareous W	Burnt shale T	Limestone L	Limestone LL	Minor additional constituents
CEM I	Portland cement	CEM I	95-100	–	–	–	–	–	–	–	–	–	0 to 5
CEM II	Portland-slag cement	CEM II/A-S	80 to 94	6 to 20	–	–	–	–	–	–	–	–	0 to 5
		CEM II/B-S	65 to 79	21 to 35	–	–	–	–	–	–	–	–	0 to 5
	Portland-silica fume cement	CEM II/A-D	90 to 94	–	6 to 10	–	–	–	–	–	–	–	0 to 5
	Portland-pozzolana cement	CEM II/A-P	80 to 94	–	–	6 to 20	–	–	–	–	–	–	0 to 5
		CEM II/B-P	65 to 79	–	–	21 to 35	–	–	–	–	–	–	0 to 5
		CEM II/A-Q	80 to 94	–	–	–	6 to 20	–	–	–	–	–	0 to 5
		CEM II/B-Q	65 to 79	–	–	–	21 to 35	–	–	–	–	–	0 to 5
	Portland-fly ash cement	CEM II/A-V	80 to 94	–	–	–	–	6 to 20	–	–	–	–	0 to 5
		CEM II/B-V	65 to 79	–	–	–	–	21 to 35	–	–	–	–	0 to 5
		CEM II/A-W	80 to 94	–	–	–	–	–	6 to 20	–	–	–	0 to 5
		CEM II/B-W	65 to 79	–	–	–	–	–	21 to 35	–	–	–	0 to 5
	Portland-burnt shale cement	CEM II/A-T	80 to 94	–	–	–	–	–	–	6 to 20	–	–	0 to 5
		CEM II/B-T	65 to 79	–	–	–	–	–	–	21 to 35	–	–	0 to 5
	Portland-limestone cement	CEM II/A-L	80 to 94	–	–	–	–	–	–	–	6 to 20	–	0 to 5
		CEM II/B-L	65 to 79	–	–	–	–	–	–	–	21 to 35	–	0 to 5
		CEM II/A-LL	80 to 94	–	–	–	–	–	–	–	–	6 to 20	0 to 5
		CEM II/B-LL	65 to 79	–	–	–	–	–	–	–	–	21 to 35	0 to 5
	Portland-composite cement [c]	CEM II/A-M	80 to 94	<—— 6 to 20 ——>									0 to 5
		CEM II/B-M	65 to 79	<—— 21 to 35 ——>									0 to 5
CEM III	Blastfurnace cement	CEM III/A	35 to 64	36 to 65	–	–	–	–	–	–	–	–	0 to 5
		CEM III/B	20 to 34	66 to 80	–	–	–	–	–	–	–	–	0 to 5
		CEM III/C	5 to 19	81 to 95	–	–	–	–	–	–	–	–	0 to 5
CEM IV	Pozzolanic cement [c]	CEM IV/A	65 to 89	–	<—— 11 to 35 ——>					–	–	–	0 to 5
		CEM IV/B	45 to 64	–	<—— 36 to 55 ——>					–	–	–	0 to 5
CEM V	Composite cement [c]	CEM V/A	40 to 64	18 to 30	–	<—— 18 to 30 ——>			–	–	–	–	0 to 5
		CEM V/B	20 to 38	31 to 50	–	<—— 31 to 50 ——>			–	–	–	–	0 to 5

[a] The values in the table refer to the sum of the main and minor additional constituents.
[b] The proportion of silica fume is limited to 10 %.
[c] In Portland-composite cements CEM II/A-M and CEM II/B-M, in Pozzolanic cements CEM IV/A and CEM IV/B and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement (for example see clause 8).

2.6 Properties of Concrete

Workability of concrete is important for fresh concrete testing to ensure the quality of hardened concrete. For the mechanical properties of concrete, compressive strength and the concrete temperature are significant. The ability of concrete to withstand axial force is referred to its compressive strength. The material is crushed when the maximum compressive strength is attained. The concrete temperature is to test the temperature change of concrete due to the heat generated during concrete hydration.

2.6.1 Workability

The energy required to reduce friction between the fresh cement paste particles is known as workability. In other word, the concrete's workability reflects how easy it is to mix, handled, and compact. A concrete in fresh state, should be able to be poured and moulded into any shape. The aggregate grading and condition, aggregate type, aggregate-to-cement ratio, water-to-cement ratio, admixture type and content, and cement fineness are elements that will affect the workability of concrete. In term of water/cement ratio, the higher the water/cement ratio, the higher the workability of fresh concrete due to the lubrication effect of water.

According to Haach, et al. (2011), poorly graded aggregates can reduce workability, but well-graded aggregates with a balanced ratio of coarse and fine particles can improve the workability of concrete. While rounded or smooth aggregates have weak interlocking which allowing particles to slip past one another, angular and rough-textured aggregates offer better interlocking and increased workability. Surface texture affects cement paste and aggregate bonding, and clean aggregate is essential to avoid impurities from interfering with the dispersion of water and cement.

The fineness of cement also significantly impacts the workability of concrete. The finer cement particles will have larger total surface area and demand more water to cover, leading to a higher water-cement ratio required to maintain same workability. Additionally, finer cement particles tend to hydrate more rapidly, potentially causing faster setting times, which can be challenging during mixing and placement, especially in warm conditions (Higginson, 1970).

In British Standards (BS8500-2:2015), concrete slumps are categorized into different classes based on their slump values, representing the workability and consistency of the concrete mixture. These slump classes correspond to various construction applications. S1, with a low slump range of 0 mm to 50 mm, suits stiff or semi-dry concrete for slipform paving and road kerbs. S2, with a moderate slump of 40 mm to 100 mm, use in general construction like foundations and pavements. High-slump S3 (90 mm to 160 mm) is ideal for pumped concrete and lightly reinforced structures. Very high-slump S4 (150 mm to 220 mm) excels in self-compacting concrete for architectural and complex formwork. Finally, extremely high-slump S5 (not less than 210 mm) is reserved for specialized applications such as intricate architectural features and heavily reinforced elements, offering extreme flow and workability properties. The choice of slump class depends on specific project requirements, considering factors like structural design, placement method, and desired workability, to ensure the concrete meets performance and durability standards. Table 2.7 shows the summary of the slump class of concrete.

Vebe test and compacting factor test are other type of testing method for workability. According to Hama & Hilal (2019), vebe test is more suitable for mixtures with lower consistency while compacting factor test is more approprite for assessing compactibility characteristics and is particularly effective for dry mixes due to its sensitivity to low-workability mixes. The workability determine by vebe test and compacting factor test is shown in Table 2.8 and Table 2.9 respectively.

Table 2.7: Summary of Slump Class.

Slump Class	**Slump (mm)**	**Application**
S1	0 - 50	Slipform paving, road kerbs
S2	40 – 100	Foundations, footings, pavements
S3	90 - 160	Pumped concrete, lightly reinforced
S4	150 - 220	Self-compacting concrete
S5	>210	Specialized architectural features, heavily reinforced

Table 2.8: Workability Classified by Vebe Time (Schneider, et al., 2020).

Workability	**Vebe (s)**
Extremely Dry	32 – 18
Very Stiff	18 – 10
Stiff	10 - 5
Stiff Plastic	5 – 3
Plastic	3 – 0
Very Plastic	-

Table 2.9: Workability Classified by Compacting Factor (Neville, 2011).

Workability	**Compacting Factor**
Very Low Workability	0.78
Low Workability	0.85
Medium Workability	0.92
High Workability	0.95

2.6.2 Density

The standard density of concrete falls within a range of 2,400 kg/m³ to 2,900 kg/m³, with variations contingent upon factors like aggregate composition, water-cement ratio, and curing circumstances. In the case of normal weight concrete, its density typically falls between range of 2,400 kg/m³ to 2,900 kg/m³ (HOUSING NEWS DESK, 2023). The density of concrete significantly impacts its mechanical characteristics. A denser concrete typically results in greater strength and a reduced presence of voids and porosity. When concrete has fewer voids, it becomes less permeable to water and soluble substances. Consequently, it exhibits lower water absorption, leading to enhanced durability in such concrete formulations (Iffat, 2015).

2.6.3 Initial Setting Time

Concrete setting describes the stiffening of cement paste. In other word, setting indicate the transition of cement paste from a fluid state to a rigid one. Strength is gained during setting, it's crucial to distinguish it from hardening, which refers to the ongoing strength development of the set paste. Initial set and final set are used to mark specific stages of setting.

The concrete setting is usually cause by the chemical component in the cement. Among the components, C_3A and C_3S will react first. C_3A will be contributing for its rapid setting properties, however it can be controlled by the addition of gypsum. This delays the formation of calcium aluminate hydrate, allowing C_3S to set first. Pure C_3S also exhibits an initial set when mixed with water, while C2S stiffens more gradually (Neville, 2011).

During hydration of cement, the framework of the hydrated cement paste is established primarily by calcium silicate hydrate (CSH). If C_3A were allowed to set first, it would form a rather porous calcium aluminate hydrate structure. Subsequent hydration of remaining cement compounds within this porous network would negatively impact the overall strength of the paste. The development of setting might involve factors other than the rapid formation of crystalline products. The formation of films around cement particles and a mutual coagulation of components within the paste have also been proposed as contributing factors.

2.6.4 Concrete Compressive Strength

Concrete compressive strength refers to the capacity of concrete to withstand axial loads. It is a fundamental property used to evaluate the quality and performance of concrete in structural applications. Compressive strength is typically measured in megapascals (MPa) and is determined through standardized laboratory tests. The test for concrete compressive strength involves casting cylindrical or concrete cube sample, curing them before testing, and subjecting them to a gradually applied axial load until the concrete fails by crushing. The peak load at failure is recorded, and the compressive strength is calculated by dividing this load by the cross-sectional area of the specimen. For concrete with strength range from 20 MPa – 50 MPa is usually considered as normal strength concrete, high-strength concrete is typically range from 50 MPa – 80 MPa, and concrete above 80 MPa is consider as ultra-high strength concrete. Concrete compressive strength is a critical parameter in construction and engineering projects, as it influences the design of structural elements, such as columns, beams, and foundations. It is essential to meet or exceed specified compressive strength requirements to ensure the safety and durability of concrete structures. Compressive strength can be influenced by factors such as the mix design, curing conditions, and the type and quality of materials used in the concrete mixture.

2.6.5 Concrete Temperature

The change in concrete temperature over time refers to the variation in the temperature of concrete as it undergoes the process of setting and curing. Concrete temperature can change significantly during these stages due to various factors such as the initial mixing temperature, ambient temperature, curing methods, and the heat generated by the hydration reactions of cement.

At the time of mixing, concrete typically has an initial temperature influenced by the temperature of its constituent materials, especially the water, cement, and aggregates. After placement, concrete begins to undergo the hydration process, where cement particles react with water to form CSH gel. This is an exothermic reaction which generates heat, known as heat of hydration, causing the concrete's temperature to rise. Over time, concrete temperature gradually decreases as it loses heat to the surrounding environment. The rate of temperature change depends on several factors, including the concrete's mass, insulation, curing conditions (e.g., moisture retention and temperature control), and the specific mix design.

Monitoring the change in concrete temperature over time is essential for ensuring proper curing and preventing issues such as thermal cracking, especially in large or mass concrete placements. Concrete temperature data is critical for construction quality control and can help optimize curing methods and schedules to achieve the desired concrete properties.

2.7 Material

Water, fine and coarse aggregate, and cement main raw materials of concrete. Hence, the following section will discuss raw materials such as Ordinary Portland Cement, fine aggregate, coarse aggregate, superplasticiser and water.

2.7.1 Cement

Ordinary Portland Cement (OPC) holds a global reputation as the most widely used cement, serving as a crucial component in mortar, concrete, and various construction materials. OPC as the most frequently used choice, with its production process utilizing superior raw materials and a specialized grinding method, resulting in superior and more consistent performance. OPC primarily consists of two key raw material categories: calcareous and argillaceous. Calcareous materials include elements like limestone, calcium, chalk, and others, while argillaceous materials include alumina, shale, slate, clay, etc. OPC is produced by subjecting clay and limestone minerals to the heat of a grinding clinker kiln, followed by the addition of 2 to 3% gypsum to create a finely powdered substance. The cement-making process involves the crushing of raw materials, blending approximately two parts of calcareous materials with one part of argillaceous materials in ball mills, under either dry or wet conditions. The resulting product, either a dry powder or wet slurry, is then subjected to high temperatures in a rotating kiln, typically ranging from 1400°C to 1500°C. Once the kiln process is complete, the resulting clinker is cooled and subsequently ground in ball mills, with gypsum introduced during this phase to attain the desired fineness according to the intended product.

OPC has several advantages, its good binding properties contribute to the structural strength of construction components. Moreover, it offers cost savings compared to other cement varieties like rapid-hardening cement, and hydrophobic cement. Furthermore, OPC has property of sulphate resistance, making it suitable for projects where mild sulphate resistance is required. Its ease of handling and setting compared to other cement types, allowing it suitable for high-rise buildings, highways, runways, as well as residential and industrial constructions. It is also recommended for use in various applications such as RCC buildings, concrete blocks, paver blocks, and more, without the need for specialized expertise.

However, there are also disadvantage associated with OPC. It is not recommended for the construction of massive structures due to its higher heat of hydration, making it less suitable than other cement types like Portland Pozzolan Cement (PPC) in terms of durability for such applications. Additionally, OPC exhibits lower resistance to chemical attacks, making it unsuitable for the construction of factories and workshops. Furthermore, many other cement varieties are more cost-effective than OPC, making it a less economically attractive option in certain situations.

2.7.2 Fine Aggregate

Sand comprises tiny rock fragments and mineral particles and occurs naturally. Depending on the source, its makeup varies. It is crucial to our everyday tasks and is regarded as one of the requirements for the growth of infrastructures. Hard granite stones are crushed to make sand; manufactured sand is artificial sand used in buildings as an alternative to river sand. Its size distinguishes it as finer than gravel and coarser than silt. It is the best sand ideal for construction because it is manufactured with the necessary gradation of fineness, shape, surface smoothness, texture, and consistency. It also strengthens the concrete by lowering segregation during placement, bleeding, honeycombing, voids, and capillaries.

Sand used to produce concrete is divided into three categories based on the proportion of each size of sand found in a sample: coarse, medium, and fine. Size might be the primary criterion for dividing materials into coarse and fine categories. Most of the sand's particles might be 150 μm to 4.75 mm in size. If most of the material is larger than 0.6 mm, it is considered coarse sand; otherwise, it is considered fine sand. Silt is made up of particles that are invisible to the human eye. Even though they provide considerable strength, fine sands are not advised for structural concrete since they make polishing the concrete's surface difficult. Additionally, since it is used in smaller quantities than other sands in concrete, it offers greater cohesiveness than coarse sand.

A sieve analysis (grading test) is utilised to acquire the particle size distribution of the sand material. There are additional applications for this study as well. For instance, it may assess if it complies with design, manufacturing control, and verification criteria. In addition, it requires much attention to the size distribution to understand how the material behaves when used frequently.

2.7.3 Coarse Aggregate

Coarse aggregates play a fundamental role in the world of concrete construction, serving as an essential component in concrete mixtures. These aggregates consist of larger particles, typically exceeding 4.75 mm to 20 mm in size, and they bring various critical attributes to concrete applications.

First and foremost, coarse aggregates provide structural integrity and stability to concrete structures. Comprising the bulk of a concrete mix, they contribute significantly to the material's load-bearing capacity. This inherent strength makes coarse aggregates indispensable for creating robust and durable concrete constructions, from foundations and highways to high-rise buildings.

Coarse aggregates also act as volume fillers within concrete mixtures. By incorporating them into the mix, it becomes possible to reduce the overall volume of cement paste required. This not only helps control construction costs but also mitigates the risk of excessive shrinkage as the concrete cures, ensuring that the material maintains its desired dimensions over time.

2.7.4 Water

Water plays an essential role in producing concrete. A chemical reaction occurs when water is added to the mixture and comes into contact with the cement. Most of the time, potable water is utilised to mix the concrete. The quality and usability of the concrete are put at risk when non-drinking water or water of uncertain purity is used. The structural qualities of concrete, such as strength and durability, are significantly decreased when contaminants are present in the water used to mix the concrete. Concrete strength may be a primary indicator of how water contaminants affect concrete quality compared to control specimens made with purified water. Numerous studies have demonstrated that using water or building next to a body of water with excessive salt weakens the concrete's compressive strength by 10 to 30 %. Compared to concrete made using purified water, concrete's strength has decreased. The high chloride concentration of water causes surface efflorescence, and chronic dampness, making the reinforcing steel susceptible to corrosion. The lean mix issue, which affects concrete constructions because of poor water quality, is especially severe in tropical areas.

Additionally, the properties of the concrete are unaffected if the mixing water contains suspended particles up to 0.02 per cent by weight of the total water used in the concrete. Many dispersed particles are discovered to alter the concrete's other qualities but not its strength. Additionally, the salt concentration in water negatively impacts the concrete's strength. Salts of manganese, tin, lead, copper, and zinc are among the most common salts that may be found in water. The increase in concrete strength is slowed down by zinc chloride in water.

Moreover, the pH range best for making concrete is typically between 6 and 8. It is stated that the finest water for the building is comparable to drinking water. Also, algae are seen on the aggregates' surface and in the water used for mixing. Due to the significant amounts of air entrainment caused by 24 the algae entering the mix through the water, the strength of the concrete will be decreased.

2.7.5 Superplasticiser

According to ASTM C494/C494M (2019), high-range water reducing (superplasticizer) is classified as Type F and G. Superplasticizers (SP) are admixtures introduced in extremely small amounts to the concrete mixture. The amount of superplasticizer incorporated into concrete significantly affects the performance of concrete. Superplasticizer is commonly utilised in concrete and has become a standard component of concrete. Superplasticizers enhance the fluidity of concrete by spreading the cement particles inside the mixture. Their incorporation significantly improves the mixture's workability.

Hamouda (2015) pointed out that with an increase in the amount of superplasticizer, the workability of concrete is greatly enhanced. Because the water-reducing chemical generates the same electrostatic charge on the cement particles' surface, it causes cement particles to repel one another, preventing agglomeration and minimising air entrainment. Thus, the concrete particles become easier to move around, and water that is not limited by the flocculation system can be used to lubricate the mixture, which makes the mixture easier to work with. As a result, the workability increases.

2.8 Previous Research

Research on the properties of concrete with various brands of cement has been conducted in several countries. Nigeria has been particularly active in this regard, with detailed comparative studies on concrete properties using different cement brands conducted by researchers like Yola, et al. (2021), Arimanwa, et al. (2016) and Anejo, et al. (2014). According to Anejo, et al. (2014), among the cement brand in Negeria with w/c ratio of 0.4, Ashaka, Sokoto, and Dangote brands all achieved a shared compressive strength of 33.5 Mpa after 28 days, while Rhino cement reached higest a strength of 34 MPa, Elephant reached lowest strenght of 23.5MPa. In Arimanwa, et al. (2016) research the with various control point, cement brand of DANGOTE, UNICEM, LAFARGE, reached strength between 20-22 MPa, IBETO reaches highest strength of 27.96 MPa, similar to Arimanwa, et al. (2016) research, the Elephant brand reach lowest strenght.

Additionally, studies in Nigeria have explored the effects of elevated temperatures on concrete properties using various brands of Ordinary Portland Cement (OPC) by Dahiru, et al. (2019). From the research, it is found that the cement brand Bua reaches the highest strength no metter in control condition, or in elevated temperature of 800 °C and 1000 °C. Moreover, according to the impact of calcium chloride on concrete properties, as investigated by Odeyemi, et al. (2015), with calcium chloride in the concrete, the Burham cement achieve highest strength while Dangote Cement reach highest strength without calcium chloride.

The quality of different cement brands in Bangladesh was extensively examined by Mohammed (2007). It shows that the cement with 95% - 100% clinker and 0% - 5% gypsum shows highest strength at 28-day. Pakistan has seen studies on the behaviour of concrete with various cement brands, led by researchers like Soltani, et al. (2019). According to the research, among cement brand Lucky, Black bull, DG and Pak Land in Pakistan, with w/c ration of 0.45, the Lucky brand shows the best performance in compressive strength which is 31 MPa in 28-day. In India, Bhamere (2016) conducted comparative studies on concrete strength using different cement brands. Among 10 brand type of cement, the cement label as sample 2 gain highest strength in 3-day while sample 5 gain highest strength in 7-day. These studies contribute to a broader understanding of how different cement brands influence concrete properties in diverse geographic contexts. However, there is no similar research found in Malysia.

2.9 Summary

There are many brands and types of cement on the market, each with unique properties that can significantly affect the performance of concrete. These different cement types are for specific applications and construction scenarios, so the selection process is critical to achieving the desired results. The choice of cement type can have a significant impact on the concrete's workability, density, compressive strength, and even the temperature during curing. Therefore, understanding the performance and characteristics of different cement brands and types is critical to ensuring that concrete formulations meet project requirements and performance expectations.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The study's methodology is covered in this chapter. This chapter will provide information on the raw materials required for the research, the proposed mixing proportion, the procedure for preparing the testing specimens, and the laboratory tests conducted to address the study's objectives. The entire research process includes the general introduction, literature review, methodology, laboratory testing, data analysis, and conclusion. To ensure the consistency and accuracy of the data, all procedures will be following BS EN and ASTM standards.

3.2 Flow Chart of the Study

Figure 3.1 shows the flow chart of overall study.

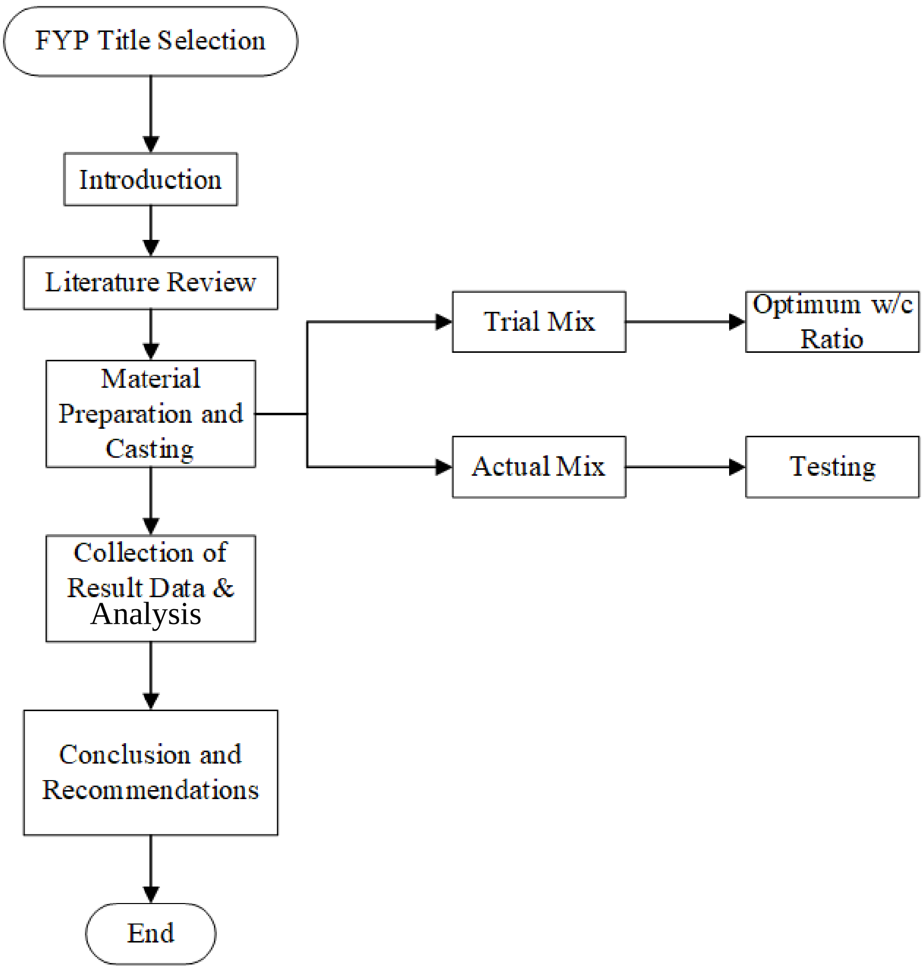

Figure 3.1: Flowchart of Overall Project.

3.3 Raw Material

This study used materials including cement, coarse aggregate, fine aggregates, water and superplasticizer.

3.3.1 Cement

There are four types of cement were used in this study which are Ordinary Portland Cement (OPC) with grade 42.5N and 52.5N, Portland Limestone Cement with grade 32.5N and Pulverised Fly Ash Cement with grade 32.5N. These cements will be represented by a simplified name and the simplified name will be used throughout this report. The represented simplified name of four types of cement is shown in Table 3.1.

Table 3.1: The Represented Simplified Name of Four Types of Cement.

Cement Type	**Represented Simplified Name**
Ordinary Portland Cement with Grade 42.5N	OPC 42.5N
Ordinary Portland Cement with Grade 52.5N	OPC 52.5N
Portland Limestone Cement with Grade 32.5N	PLC 32.5N
Pulverised Fly Ash Cement with Grade 32.5N	PFA 32.5N

OPC 42.5N

OPC 42.5N is Type I Ordinary Portland Cement (OPC) with the Malaysia standard of MS EN 197-1:2014 CEM I 42.5 N, and it was used as control mix in this study. The brand of the cement is “Tasek”. The “Tasek” branded cement is shown in Figure 3.2. Table 3.2 shows the chemical oxide composition of OPC 42.5N which obtain from the X-ray fluorescence test (XRF). The XRD chemical analysis is shown in Appendix A-2 and the result is tabulated in Table 3.3.

Figure 3.2: “Tasek” Branded Ordinary Portland Cement.

Table 3.2: Chemical Oxide Composition of OPC 42.5N form XRF.

Oxide	Composition (%)
MgO	0.83
Al_2O_3	2.03
SiO_2	11.95
P_2O_5	0.56
SO_3	3.29
K2O	0.33
CaO	80.00
TiO_2	0.24
MnO	0.08
Fe_2O_3	5.20
Others	0.48

Table 3.3: Chemical Composition of OPC 42.5N in from XRD.

Chemical Composition	Percentage (%)
Brownmillerite	6.0
Celite	8.0
Belite	15.0
Alite	52.0
Calcium Carbonate	10.0
Lime	4.0
Gypsum	2.0
Periclase	3.0

OPC 52.5N

OPC 52.5N is Type I Ordinary Portland Cement (OPC) with the Malaysia standard of MS EN 197-1:2014 CEM I 52.5 N. The brand of the cement is "Orang Kuat" from YTL Cement Sdn Bhd. The "Orang Kuat" branded cement is shown in Figure 3.3 and the chemical oxide composition of OPC 52.5N which obtain from the X-ray fluorescence test (XRF) is shown in Table 3.4. The XRD chemical analysis is shown in Appendix A-3 and the result is tabulated in Table 3.5.

Figure 3.3: "Orang Kuat" Branded Ordinary Portland Cement.

Table 3.4: Chemical Oxide Composition of OPC 52.5N form XRF.

Oxide	**Composition (%)**
MgO	0.70
Al_2O_3	1.90
SiO_2	12.30
P_2O_5	0.54
SO_3	3.59
K2O	0.87
CaO	74.30
TiO_2	0.29
MnO	0.07
Fe_2O_3	5.32
Others	0.19

Table 3.5: Chemical Composition of OPC 52.5N in from XRD.

Composition	Percentage (%)
Celite	10.0
Periclase	3.0
Gypsum	2.0
Alite	55.0
Belite	12.0
Lime	2.0
Calcium Carbonate	9.0
Brownmillerite	7.0

PLC 32.5N

PLC 32.5N is Type II Portland Composite Cement (PLC) with the Malaysia standard of MS EN 197-1:2014 CEM II / B-L 32.5N. The brand of the cement is "Castle" from YTL Cement Sdn Bhd. Figure 3.4 illustrates the "Castle" branded cement and the chemical oxide composition of PLC 32.5N which obtain from the X-ray fluorescence test (XRF) is shown in Table 3.6. The XRD chemical analysis is shown in Appendix A-4 and the result is tabulated in Table 3.7.

Figure 3.4: "Castle" Branded Portland Limestone Cement.

Table 3.6: Chemical Oxide Composition of PLC 32.5N form XRF.

Oxide	Composition (%)
MgO	0.66
Al_2O_3	1.66
SiO_2	7.95
P_2O_5	0.59
SO_3	2.75
K2O	0.99
CaO	81.05
TiO_2	0.11
MnO	0.18
Fe_2O_3	3.86
Others	0.19

Table 3.7: Chemical Composition of PLC 32.5N in from XRD.

Composition	Percentage (%)
Aluminium Oxide	4.0
Alite	43.0
Iron Oxide	3.0
Belite	14.0
Brownmillerite	7.0
Periclase	3.0
Calcite	18.0
Celite	8.0

PFA 32.5N

PFA 32.5N is Type II Portland Composite Cement (PCC) with the Malaysia standard of MS EN 197-1:2014 CEM II/B-L 32.5N. It is a fly ash blended composite cement. The brand of the cement is “Phoenix” from YTL Cement Sdn Bhd. Figure 3.5 illustrates the “Phoenix” branded cement and the chemical oxide composition of PLC 32.5N which obtain from the X-ray fluorescence test (XRF) is shown in Table 3.8. The XRD chemical analysis is shown in Appendix A-5 and the result is tabulated in Table 3.9.

Figure 3.5: “Phoenix” Branded Fly Ash Blended Cement.

Table 3.8: Chemical Oxide Composition of PFA 32.5N form XRF.

Oxide	Composition (%)
MgO	0.25
Al_2O_3	4.44
SiO_2	17.40
P_2O_5	0.73
SO_3	1.75
K2O	1.05
CaO	67.40
TiO_2	0.62
MnO	0.17
Fe_2O_3	5.71
Others	0.49

Table 3.9: Chemical Composition of PFA 32.5N in from XRD.

Composition	Percentage (%)
Silicon Dioxide	18.8
Celite	5.9
Brownmillerite	11.4
Belite	11.9
Alite	44.5
Aluminium Oxide	3.0
Periclase	1.0
Aluminium Oxide	3.0

Before mixing, 300-micron meter sieve was used to sieve the cement before storing as illustrated in Figure 3.6 to remove any lumps in the cement powder. The cement was then store in the air-tight container as shown in Figure 3.7, to prevent moisture exposure, which will cause the cement to hydrate.

Figure 3.6: Sieving of Cement through 300-micron sieve.

Figure 3.7: Air-Tight Container.

3.3.2 Fine Aggregate and Coarse Aggregate

The preparation of aggregate is following the ASTM C33 standard (2018). The fine aggregate used in mixing is sand with fineness modulus of 2.18. The sand sample will be sieved through 4.75 mm sieve and particle that remain on it will be removed as it is consider as coarse particle. Figure 3.8 shows the sieving of sand through 4.75 mm sieve and the prepared sand is shown in Figure 3.9.

Figure 3.8: Sieving of Sand through 4.75 mm Sieve.

Figure 3.9: Prepared Sand.

For coarse aggregates, a 3/4 inches aggregate with a specific gravity of 7.06 were used in this study. 20 mm sieve, 10 mm sieve, and 1.18 mm sieve were used to sieved the coarse aggregate. To get the desired size of coarse aggregate, particle that passes through 1.18 mm sieve and remains at 20 mm sieve will be removed. The aggregates that pass through 20 mm sieve and retain on 10 mm sieve will be stored separately from those passes through 10mm sieve and retain on 1.18 mm sieve, as the design mix proportion required aggregate from both size with different ratio. The coarse aggregate was washed with water and air dried so that it reaches the saturated surface dry (SSD) condition. Figure 3.10 shows the air dried of coarse aggregate and the prepared coarse aggregate with 20 mm and 10 mm in size are show in Figure 3.11 and Figure 3.12 respectively.

Figure 3.10: Air Dried of Coarse Aggregate after Washing.

Figure 3.11: Prepared 20 mm Coarse Aggregate.

Figure 3.12: Prepared 10 mm Coarse Aggregate.

3.3.3 Water and Superplasticiser

The water used is based on the ASTM C1602/C1602M (2022) Standard. To ensure the quality of concrete's hydration process and achieve subsequent strength, the use of water should be free from sediments, impurities, and chemicals. The assumed specific gravity of the water utilized is 1.0, and it must be maintained at a temperature consistent with room conditions, approximately 27°C, and it must be maintained at a temperature consistent with room conditions, approximately 27°C. The water was used for concrete mixing and curing process.

The superplasticiser (SP) was introduced as a water-reducing agent and thoroughly blended into the concrete mix. The purpose of using superplasticizer was to ensure the excellent workability of the fresh concrete while retaining its strength. The quantity of superplasticiser applied was adjusted based on the proportions of water incorporated into the concrete mix. The SP used in this study is MasterGlenium ACE 8538 which supplied by Master Builder Solution Malaysia Sdn Bhd as shown in Figure 3.13. MasterGlenium ACE 8538 is a high-range superplasticizer containing polycarboxylate ether polymers that devoid of chloride and has been formulated to meet the specifications outlined in ASTM C494 for Type A and Type F admixtures (Sika, n.d.).

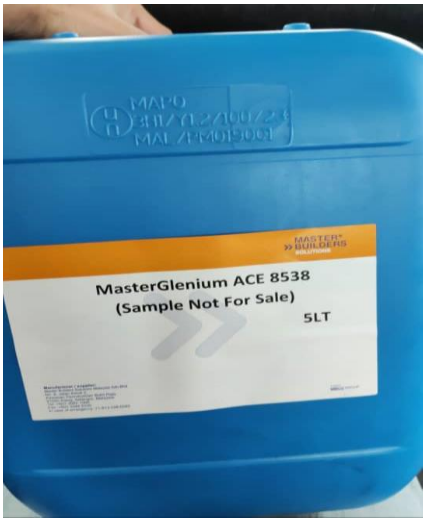

Figure 3.13: Superplasticiser.

3.4 Sieve Analysis

Sieve analysis is a method used to assess the gradation of aggregates by analysing the distribution of particle sizes. The distribution of aggregate particles is essential to ensure the quality of concrete. The testing procedure was following the ASTM C136 standard (2014).

For fine aggregate, first, an oven-dried sample weighing 500 grams was initially placed onto a tray. Next, a series of test sieves was arranged and stacked on a shaker. These sieves were organized with the largest aperture size (4.75 mm) positioned at the top, while the smallest (0.15 mm) was placed at the bottom. The 500-gram sand sample was then poured onto the uppermost sieve. To prevent fine sand particles from dispersing into the air, the top of the stack was covered with a sieve pan. The sieves were securely fastened onto the shaker.

Then, the power supply was turned on for a 15-minute duration to ensure thorough shaking, thus preventing excessive agitation that could potentially degrade the sand. Subsequently, the retained sand particles in each sieve were weighed, and the proportion of the entire sample that passed through each sieve was calculated based on weight. Finally, various data points were recorded and computed, including the weight of the aggregate retained in grams, the weight of the aggregate retained as a percentage, the cumulative percentage of coarser particle grains, the cumulative percentage of finer particle grains, and fineness modulus of aggregate sample.

The testing procedure will be repeated by replacing the fine aggregate to 1000 gram of over-dried coarse aggregate. And the sieve will be replaced to larger size which is the largest (28 mm) at top and the smallest (5 mm) at bottom of the stack.

Figure 3.14: Set up of Sieve Analysis Test.

The result of sieve analysis for fine and coarse aggregate are tabulated in Appendix B-1 and Appendix B-2 respectively. The grading curve was then plotted for fine and coarse aggregate as shown in Figure 3.15 and Figure 3.16 respectively. The calculated fineness modulus of fine and coarse aggregate is tabulated in Table 3.10.

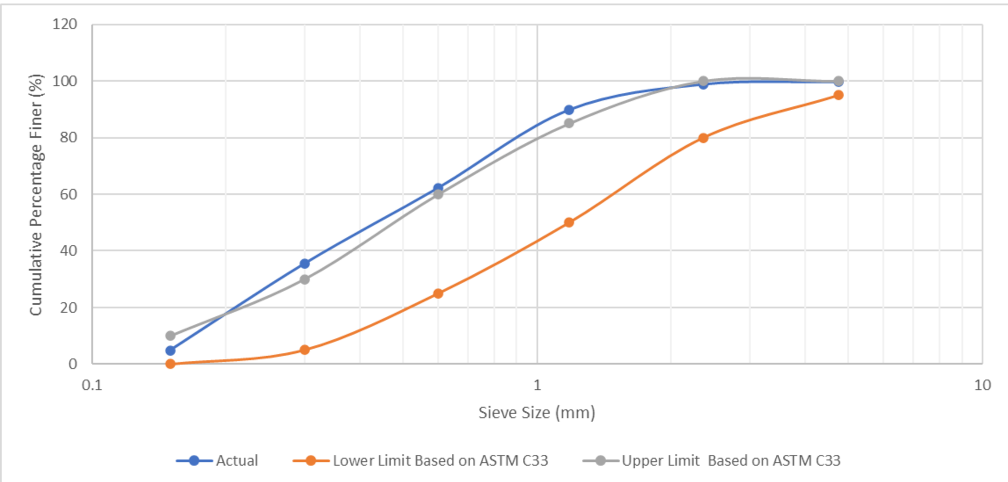

Figure 3.15: Grading Curve for Fine Aggregate.

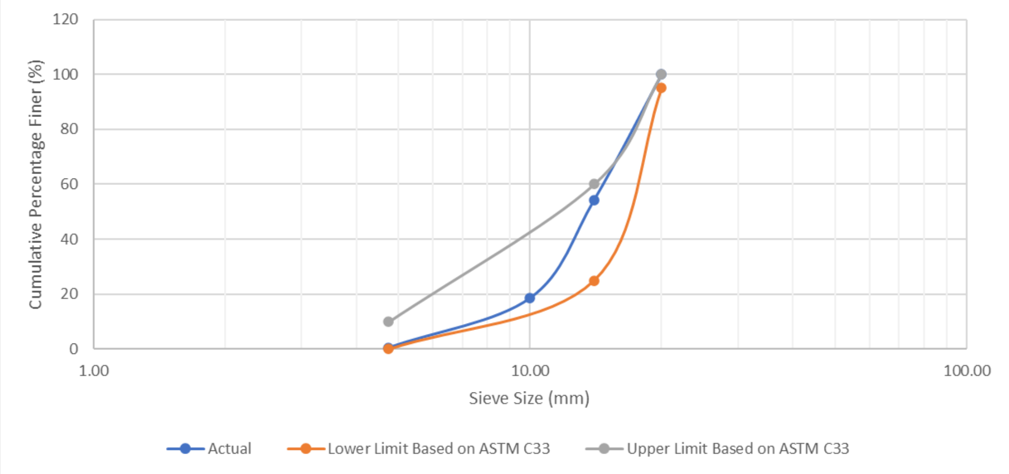

Figure 3.16: Grading Curve for Coarse Aggregate.

Table 3.10: Fineness Modulus of Fine and Coarse Aggregate.

Material	Fineness Modulus
Fine Aggregate	2.09
Coarse Aggregate	7.27

From the grading curve plotted for fine and coarse aggregate, the curve for both fine and coarse aggregate are compared with the upper and lower limit from ASTM C33. It can be seen that most of the proportion of fine aggregate exceed the upper limit of ACTM C33 which indicate that the sand is a coarse sand this may affect the strength of the concrete. For coarse aggregate, most of the particle fall between the upper and lower limit of ACTM C33.

3.5 Specific Gravity of Cement

The specific gravity test of cement is used to determine the specific gravity (relative density) of cement, which is a measure of its density compared to the density of water. The specific ASTM standard for the specific gravity test of cement is ASTM C188. First, the Le Chatelier flask as shown in Figure 3.17 was weighed empty flask with its stopper, this weight was recorded as W1. A sample of cement (around 50 grams) was carefully introduced into the flask, the flask was then weighed again with the cement and stopper, recording this weight as W2. Next, the turpentine shown in Figure 3.18 was added to the flask until it was full. A gentle swirling motion was used to remove any trapped air bubbles between the cement particles, the flask was weighed with the cement and turpentine together as shown in Figure 3.19, recording this weight as W3. Lastly, the flask was emptied completely and filled with turpentine only up to the same level used in step 3. The flask filled with turpentine was weighed, recording this weight as W4. The specific gravity of cement can be calculated by formula:

$$SG = \frac{W2-W1}{(W2-W1)-(W3-W4)\times 0.871} \tag{3.1}$$

The result of specific gravity test for OPC 42.5N, are tabulated in Table 3.12. It can be seen that OPC 42.5N has highest specific gravity, follow by OPC 52.5N, PFA 32.5N and PLC 32.5N.

Figure 3.17: Le Chatelier Flask.

Figure 3.18: Turpentine.

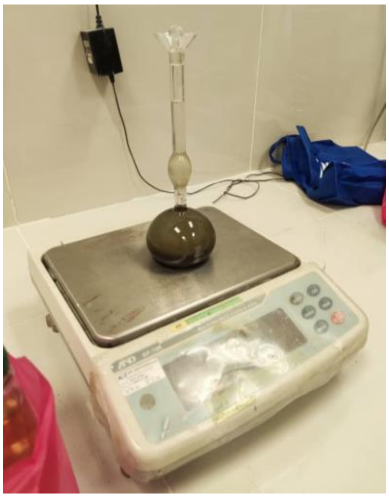

Figure 3.19: Weighing of Flask with Turpentine and Cement.

Table 3.11: Result of Specific Gravity Test of Cement.

Cement	Weight (g)				Specific Gravity
	W1	W2	W3	W4	
OPC 42.5N	120.86	170.89	376.32	336.71	3.22
OPC 52.5N	121.16	171.16	375.88	337.05	3.09
PLC 32.5N	121.17	171.16	372.07	337.04	2.57
PFA 32.5N	121.10	171.18	372.54	336.95	2.62

3.6 Concrete Mould

The mould dimension is according to the standards specified in BS EN 12390-1 (2021) and ASTM C31/C31M (2022). Various concrete moulds were used to prepare concrete sample for different property test. The compression test utilized cube (150 × 150 ×150) mm moulds and cylinder mould of 200 mm height × 100 mm diameter as shown in Figure 3.20 and Figure 3.21 respectively. The cube mould was also used in the temperature testing but with larger size, it is shown in Figure 3.22. Detailed information regarding each mould's dimensions and its corresponding test can be found in Table 3.13.

Figure 3.20: Cube Mould (150 × 150 × 150) mm.

Figure 3.21: Cylinder Mould (200 mm Height × 100 mm Diameter).

Figure 3.22: Cube Mould (250 × 250 × 250) mm.

Table 3.12: Dimension of Mould Used in Different Test.

Mould	Dimension (mm)	Test
Cube	150 × 150 × 150	Compressive Cube Strength Test
	250 × 250 × 250	Temperature of Concrete Test
Cylinder	200 height × 100 Diameter	Compressive Cylinder Strength Test

Before pouring the fresh concrete into the moulds, it is essential to thoroughly clean them using a scraper and a brush to eliminate any residual material. Furthermore, the moulds should be securely fastened using a spanner and then given a final cleaning using an air blower. Next, a thin layer of oil should be evenly applied to the inner surface of the moulds using a brush to ensure easy demoulding.

3.7 Trial Mix

Trial mix is important in order to get the proper water/cement ratio and SP dosage of concrete mix to slump value of 60 mm to 180 mm and reach 67MPa of compressive cube strength at 28 days. The OPC 42.5N was used for trial mix. The concretes were casted with water/cement (w/c) ratio ranging from 0.26 to 0.34 with 0.02 increment of each mix proportion. The concrete samples were cured in water for 7 and 28 days prior to carry out the 7 day and 28 days strength test. The outcomes of the compression strength tests were documented for each mix ratio, and a graphical representation was generated to determine the mix proportion that exhibited the highest compressive strength. This process allowed for the determination of the ideal water-cement ratio. This procedure was also implemented to ensure uniformity and reliability in the results. Appendix A-1 shows the design of concrete mix proportion according to Design of Normal Concrete Mixes Second Edition.

3.8 Mixing Procedure

In this study, the mixing process was conducted using a concrete mixer as shown in Figure 3.23. Standard refer to ASTM C192/192M (2015). Before mixing, the initial step involved weighing the required quantities of OPC, sand, coarse aggregate, and superplasticizer, using a precision weighing machine to achieve specific mix proportions. Next, all the components, including cement, fine aggregate, coarse aggregate, were combined in the concrete mixer and thoroughly mixed to create the dry mix. Next, superplasticiser was added to the water, and this mixture was gradually poured into the dry mix in stages. The mixing continued until a uniform mortar was formed. The mix with OPC 42.5N cement will be used as control mix, and the mixing procedure was repeated by replacing the OPC 42.5N with different type on cement which mention in previous sub-chapter with the same mix proportion as control mix.

Figure 3.23: Concrete Mixer.

3.9 Casting Procedure

After mixing of concrete, the freshly mixed concrete was poured into concrete moulds. Standard refer to ASTM C192/192M (2015). The compression cube strength test was carried out using a cubic mould measuring 150 mm × 150 mm × 150 mm. Before pouring the concrete, the precautious steps were essential, this involved cleaning, securely fastening, and applying a thin coating of oil to all the moulds. The concrete was then poured to the moulds in three distinct layers, with each layer subjected to 25 tamping rod strokes of standard 5/8 inches diameter to eliminate any trapped air within the fresh concrete. Subsequently, the freshly mixed concrete was left undisturbed in the moulds overnight to allow for proper setting.

3.10 Fresh Concrete Properties Test

The concrete was tested during its fresh state to ensure the workability as well as quality of concrete. For workability test, slump cone test, vebe test and compacting factor test were carried out. Other than that, the initial setting time test and concrete temperature test was also conducted during the fresh state of concrete.

3.10.1 Slump Test

Slump testing was conducted following the guidelines outlined in ASTM C143/C143M (2020). The equipment used included a steel tamping rod with a diameter of 5/8 inches and a length of 24 inches, a large pan, a slump cone, a trowel, and a ruler.

The slump cone, which had a height of 300 mm, was positioned on a flat surface. Its 200 mm diameter base was placed on a level surface, with a smaller 100 mm diameter opening at the top. Fresh concrete was then poured into the slump cone in three separate layers, with approximately one-third of the cone volume allocated to each layer. To consolidate the fresh concrete mix, the tamping rod was used to tap it with 25 even strokes in each layer. After the concrete fully occupied the volume of slump cone, any excess fresh concrete on the top surface was removed.

The slump cone was carefully lifted in a vertical direction. Finally, the slump cone was placed adjacent to the slumped concrete, and a tamping rod was positioned on top of the cone. The difference in height between the slump cone and the slumped concrete was used to determine the slump value. It's important to emphasize that the slump value needed to be determined immediately after removing the slump cone. It is recommended to complete the slump cone test procedure without delay of time to prevent excessive water evaporate from the mix and affect the accuracy of the result. Figure 3.24 shows the slump test.

Figure 3.24: Slump Test.

3.10.2 Vebe Test

The Vebe test was outlined in BS EN 12350-3:2009, is a procedure used for assessing the workability of freshly mixed concrete. To conduct this test, a set of essential equipment and materials is required, including a vibrating Table as shown in Figure 3.25, a slump cone, a stopwatch, and a tamping rod.

Figure 3.25: Vebe Vibrating Table.

The testing procedure begins with the preparation of a representative sample of freshly mixed concrete. The slump cone is securely placed on the vibrating table, ensuring it is level and stable. The concrete is then carefully filled into the slump cone and at this stage, no consolidation of the concrete is performed.

The vibrating table is activated, and the concrete begins to settle or compact due to the vibration. The test measures the time it takes for the concrete to reach a specific level of compaction, which referred to the Vebe time. This time duration is recorded as an indicator of the concrete's workability. This duration is recorded in seconds and serves as a key indicator of the concrete's workability. Shorter Vebe times indicate higher workability.

3.10.3 Compacting Factor

The compacting factor test served as an additional method for assessing the workability of freshly mixed concrete. This test adhered to the guidelines outlined in BS EN 12350-4 (2019). Its objective was to evaluate the flowability of fresh concrete and its capacity to fill all spaces within the formwork without experiencing segregation or bleeding. The test determined the ratio between the weight of fully compacted concrete and partially compacted concrete. Initially, the fresh concrete was poured into the upper hopper until it reached full capacity. Subsequently, the trapdoor of the upper hopper was opened to allow the concrete to descend into the lower hopper. Following this, the trapdoor of the lower hopper was opened to enable the concrete to fill a standard cylindrical mould. The fresh concrete within the cylinder was then compacted using a tamping rod until full compaction was achieved. The cylinder containing the fully compacted concrete was weighed. The process was repeated without compacting the concrete within the cylinder. The cylinder with partially compacted concrete was then weighed. Finally, the compacting factor was determined using Equation 3.2 as specified. Figure 3.26 illustrates the apparatus utilized for conducting the compacting factor test.

$$Compacting\ Factor = \frac{Partially\ Compacted\ Concrete}{FullyCompacted\ Concrete} \tag{3.2}$$

Figure 3.26: Compacting Factor Test.

3.10.4 Initial Setting Test

The initial setting time test is following the ASTM C403/ C403M-08 (2009). The setting time of concrete is measured by concrete penetrometer as shown in Figure 3.27 by the penetration resistance. The penetration resistance of a cementitious material generally increases over time as the hydration progress undergo. This process involves the reaction between cement and water, leading to the formation of a binding gel that holds the material together. The rate of this increase in penetration resistance can be used to indirectly assess the setting time of the material.

First, before carrying out the test, the bleed water on top of concrete had to be removed. The needle of concrete penetrometer was inserted vertically from top of concrete until it penetrates the concrete to the depth of 25 mm ± 2mm for 10 s ± 2 s as illustrated in Figure 3.28. The penetration resistance was recorded to find out the setting time of concrete. The minimum distance between any needle impression and the container's side should be 25 mm, while the maximum should not exceed 50 mm. The first reading was taken 1 hour after the placement of fresh concrete, the subsequent readings were taken every 0.5 hours until it reaches initial set. The initial setting time is the time when the penetration resistance reaches 500 psi. The penetration resistance against time interval graph was plotted to determine the initial setting time of concrete.

Figure 3.27: Concrete Penetrometer.

Figure 3.28: Inserting Penetrometer to the Concrete.

3.10.5 Concrete Temperature Test

For the temperature test of concrete, the concrete was casted in 250 mm × 250 mm × 250 mm cube mould. The temperature will be recorded during the fresh state of concrete. The mould was sealed to prevent extra heat loss during the hydration of concrete. During the testing, the thermometer was insert into the core of fresh concrete for 1-2 minute to in order to the accurate result. The temperature of concrete was recorded in 15-minute interval for the first two hours and after 2 hours, the temperature was recorded in 30-minutes interval until the temperature reaches the highest temperature and drop. After recording all the data, the graph of temperature of concrete over time was plotted. Figure 3.29 shows the measuring of concrete temperature during hydration process.

Figure 3.29: Measuring of Concrete Temperature.

3.11 Curing

For the freshly cast concrete to become stronger, curing is essential. Curing the concrete can prevent moisture loss while supplying a continuous humidity stream for hydration. The water curing method was adopted in this research. The hardened concrete samples were weighed to assess the hardened density before curing. The hardened concretes were demoulded after 24 hours. Then, concrete samples were fully submerged in the water as shown in Figure 3.30. The water temperature was maintained between 25 °C to 30 °C. Before performing the corresponding properties tests, concrete samples were cured for 7, 28, abd 56 days, respectively. Standard refer to ASTM C192/192M (2015).

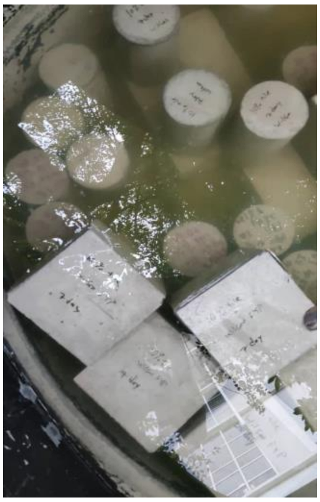

Figure 3.30: Curing of Concrete.

3.11.1 Compressive Strength Test

The compression test was performed as per BS EN 12390-3 (2019). The cubic and cylindrical specimens were required for the compression test. Before testing, the concrete was air-dried to remove moisture on concrete after being removed from the water tank. Then, the specimens' weight and dimension were measured using a Vernier calliper and digital weighing scale, respectively. For cylinder concrete, both surfaces should be ensured smooth and even therefore the grinding machine will be used to grind the top surface of concrete cylinder as shown in Figure 3.31. The test was conducted utilising the universal compression test machine under a loading rate of 6 kN/s. The centre of the concrete specimen was placed aligned with the base plate of the machine. The specimen was then loaded at a constant rate until it broke. When that happens, the maximum load was written down to calculate the compressive strength based on Equation 3.3. The compressive cube and cylinder strength are shown in Figure 3.32 and Figure 3.33 respectively.

$$fc = F/Ac \tag{3.3}$$

where,

fc = compressive strength, MPa

F = maximum load subjected to the specimen, N

Ac = cross sectional area of the specimen subjected to applied load, m^2

Figure 3.31: Grinder.

Figure 3.32: Compressive Cube Strength Test.

Figure 3.33: Compressive Cylinder Strength Test.

3.12 X-ray Diffraction Analysis (XRD)

X-ray diffraction (XRD) is a widely employed method for assessing the phase composition of both anhydrous and hydrated cementitious materials. Typically, it enables quantitative phase analysis with a level of accuracy that is considered reasonable (Matos, et al., 2022). The XRD test is referring to ASTM E3294-22.

XRD analysis is to find out chemical oxide composition of cement powder and cement paste for OPC 42.5N, OPC 52.2N, PLC 32.5N and PFA 32.5N in this study. To prepare the sample for cement paste, the cement will be mix with water only to form cement paste and allow curing for 3 days, after that the hardened cement paste will be crushed in to power and allow oven dry for 1 day to remove moisture before sent for XRD testing. Figure 3.34 shows the specimen prepared for XRD testing. The XRD testing will be run for full range analysis in this study. The result obtained from XRD test were analysed by using the Highscore Plus Software.

Figure 3.34: Prepared Specimen for XRD Test.

3.13 Summary

This chapter comprehensively outlines the entire study process, including the preparation of raw materials, mixing techniques, and testing methodologies. The materials used include cement, coarse and fine aggregates, water, and superplasticizer. Type of cement used include OPC 42.5N, OPC 52.5N, PLC 32.5N and PFA 32.5N. Mix proportions requiring trial mixes with water-cement (w/c) ratios of 0.34, 0.32, 0.30, 0.28, and 0.46 to attain a 28-day compressive cube strength of 67 MPa. The optimal trial mix proportion for the concrete, meeting the 67 MPa characteristic strength requirement, were selected for testing. Cubic and cylindrical specimens were employed for compressive strength tests. The curing period for each test specimen ranged from 7 days, 28 days to 56 days. All mixing and testing procedures in this study adhere to established BS and ASTM standards. XRD test were carried out to analyse the oxide composition of cement.

CHAPTER 4

TRIAL MIX

4.1 Introduction

This discusses the mix proportion, fresh density and compressive strength of the control mix which is the casted by OPC 42.5N with water/cement ratio (w/c) 0.26, 0.28, 0.30, 0.32, and 0.34. The superplasticiser (SP) content was adjusted with the w/c ratio to ensure the workability of fresh concrete which is from 0.15% to 0.35%. The 7 days and 28 days strength of the concrete from trial mix was tested, to ensure the designed strength was achieved. Based on the result obtained, the optimum concrete mix proportion was applied to concrete casted with various type of cement in actual mix.

4.2 Control Mix

The materials used for control mix including cement OPC 42.5N, fine aggregates, coarse aggregate, water, and superplasticiser. The concrete mix proportion design for the trial mix with w/c ratio of 0.26, 0.28, 0.30, 0.32, and 0.34 in Table 4.1. The dosage of superplasticiser was varied from 0.15% to 0.35% by the weight of cementitious material which is cement in this study according to w/c ratio in each mix design.

Table 4.1: Mix Proportion of Trial Mixes.

W/C Ratio	**Unit Weight (kg/m³)**					
	Water	**Cement**	**Aggregate**			**SP (%)**
			Fine	**10 mm**	**20 mm**	
0.34	225	662	465	329	658	0.17
0.32	225	703	465	329	658	0.17
	225	703	465	329	658	0.20
0.30	225	750	465	329	658	0.15
	225	750	465	329	658	0.20
0.28	225	804	465	329	658	0.23
0.26	225	865	465	329	658	0.30
	225	865	465	329	658	0.35

Note: The mix proportions are based on 1 m³ concrete volume using absolute volume method.

4.2.1 Workability

Slump cone test was carried out to assess the workability of fresh concrete. Figure 4.1 shows the result of slump test for different design mixes.

The lower the w/c ratio, the lower the workability of fresh concrete. Fresh concrete with low workability will increase the difficulty to compact and place and result in more air void in hardened concrete, and hence result in lower strength. To cater the problem of insufficient workability of fresh concrete caused by lower w/c ratio, the water-reducing chemical admixture such as superplasticiser (SP) can be added. SP can maintain the workability of fresh concrete even with low w/c ratio. In general, the higher the dosage of SP, the higher the workability of fresh concrete. Therefore, the dosage of SP should be in right amount as too low amount of SP may not sufficient to maintain the workability while too high amount of SP can cause segregation of concrete. In trial mix, the adequate amount of SP is also one of the objectives to obtain, hence the different dosages were use in the mix design to get the optimum dosage which is from 0.15% to 0.35% as shown in Table 4.1.

The desired slump value for fresh concrete is within 60 mm to 180 mm, the trial mix result that not fall within the range indicate that the mix proportion is not suitable.

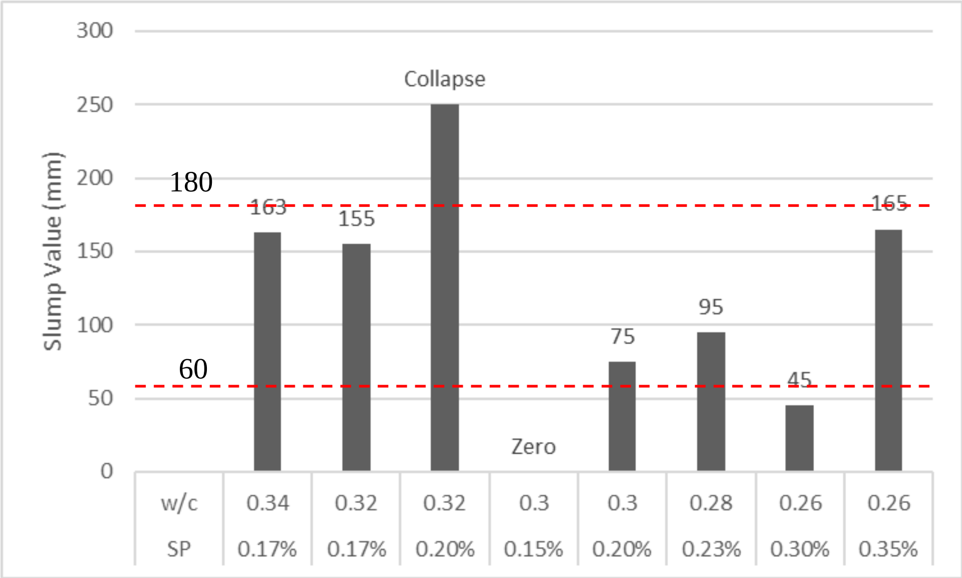

Figure 4.1: Slump Value of Trial Mixes.

4.2.2 Compressive Strength

The 7 days and 28 days of concrete compressive strength of OPC 42.5N were tested for the trial mix. The compressive strength test result for the trial mix is shown in Appendix B-3. After getting the result of compressive strength, the mix proportion design of concrete that achieve at least 67 MPa in 28 days was chosen for actual mix. Figure 4.2 shows the compressive strength of OPC 42.5N with different w/c ratio and SP dosage.

Since, the concrete casted with OPC 42.5N with w/c ratio from 0.34 to 0.28 were unable to reach the desired strength at 28 days, the mix proportion design with the w/c ratio were not applied in actual mix. The mix with w/c ratio of 0.26 achieved the desired strength, however there were 2 set of mix proportions have the w/c ratio of 0.26, one was with 0.30% of SP dosage and one was with 0.35% of SP dosage. Although both set of mix proportion achieve the desired strength, the mix with 0.35% of SP dosage was chosen as it also achieved the desired workability of fresh concrete while the other do not. Its' compressive strength was 67.91 MPa.

Therefore, the mix proportion with w/c ratio of 0.26 and SP dosage of 0.35% was chosen for actual mix.

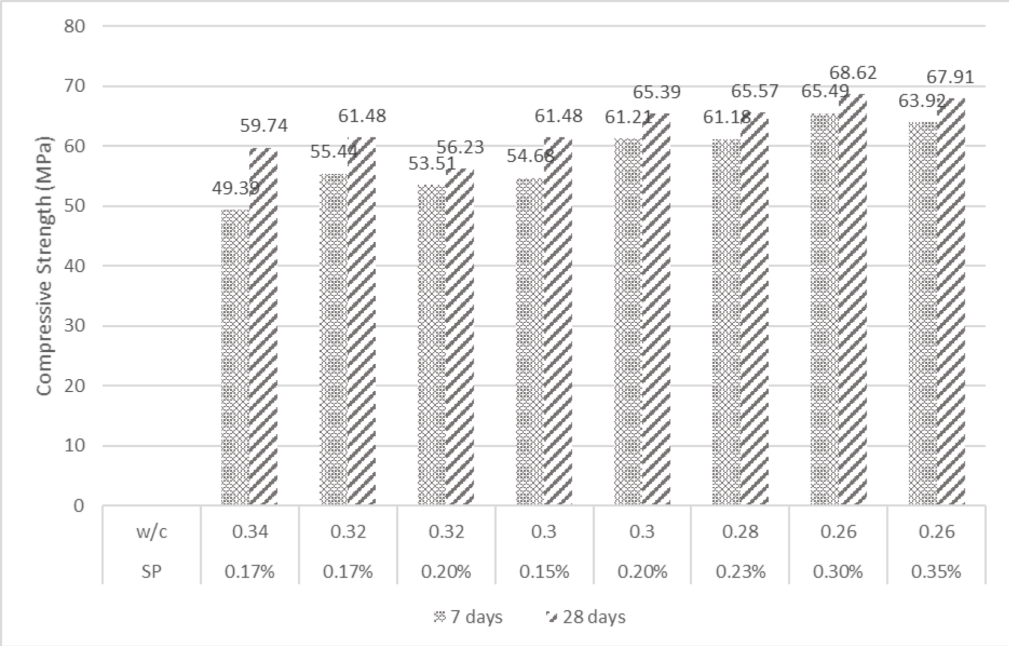

Figure 4.2: Compressive Strength of Trial Mix for OPC 42.5N.

4.3 Summary

In summary, the slump test and compressive strength test was carried out to assess the workability and compressive strength of concrete mix with different mix proportion design. Among every set of concrete with different mix proportion design, OPC 42.5N with w/c ratio of 0.26 and SP Dosage of 0.35% achieved the minimum strength of 67 MPa at 28 days which is 67.91MPa and maintain the workability in range of slump value within 60 mm to 180 mm which is 165 mm. The optimum mix proportion design was applied to actual mix.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

The outcomes of this research were discussed in this chapter to justify the objectives of this study. The optimum mix proportion design obtained from trial mix was applied to the casting of concrete with various type of cement including OPC 42.5N, OPC 52.5N, PLC 32.5N and PFA 32.5N in actual mix. The concrete properties such as fresh properties, initial setting time, compressive strength, concrete temperature, and elemental composition of hardened cement paste were discussed in this chapter. All the specimens in actual mix were cured for 7, 28 and 56 days before testing.

5.2 Actual Mix Proportions

As discussed in Chapter 4, the materials for concrete mixing including cement, water, fine aggregate, coarse aggregate, and superplasticiser (SP). The type of cement use for concrete mixing is the manipulating variable in this study which includes OPC 42.5N, OPC 52.5N, PLC 32.5N and PFA 32.5N, OPC 42.5N. The w/c ratio was 0.26 and the SP dosage was 0.35% of the cement weight. The mix proportion design for the concrete in actual mix are shown in Table 5.1. All set of concrete were sharing the same mix proportion design so that the comparison among different set can be made.

Table 5.1: Mix Proportion Design of Actual Mix.

W/C Ratio	**Unit Weight (kg/m³)**					
	Water	**Cement**	**Aggregate**			**SP (%)**
			Fine	**10 mm**	**20 mm**	
0.26	225	865	465	329	658	0.35

Note: The mix proportions are based on 1 m³ concrete volume using absolute volume method.

5.3 Fresh Properties

The fresh properties such as slump value and vebe time, of concrete casted with OPC 42.5N, OPC 52.5N, PLC 32.5N, and PFA 32.5N are shows in Figure 5.1 and compacting factor is illustrated in Figure 5.2. Figure 5.3 shows the condition of hardened concrete prepared with various type of cements. The air void condition on the surface and segregation condition can be observed in Figure 5.3. From Figure 5.3, it can be observed that there is no segregation occur in every set of concrete.

Figure 5.1 and Figure 5.2 show that OPC 42.5N has highest workability and compacting factor, follow by OPC 52.5N, PLC 32.5N, and PFA 32.5N. The result of compacting factor of the fresh cement, is tally with the workability result in slump and vebe test. It shows that the slump value of OPC 42.5N and PFA 32.5N is 210 mm and 40 mm respectively, which both are not fall within the acceptable range of 60 mm to 180 mm. For OPC 52.5N and PLC 32.5N, they both lie within the range.

For OPC 42.5N, although the slump value is high and not fall within the acceptable range of slump value, due to the SP added in the mix, the fresh concrete is sticky and still able to maintain the cohesiveness between cement paste and aggregates. Therefore, the segregation that caused by the high slump value were not occur in concrete which can be shows in Figure 5.3. Hence, the slump value for OPC 42.5N is still acceptable. Besides, due to the SP added in the mix, vebe time will become more suitable to measure the workability of fresh concrete compared to slump value.

For PFA 32.5N, the result of slump test and vebe test shows that the mix is very dry. Although the fly ashes component in the PFA 32.5N cement can increase the workability of fresh cement (Shaikuthali, et al., 2019), the increment of workability might be offset by other factors that can lower the workability and result in very low workability. The factors that may lower the workability of fresh concrete may be due to the low specific gravity as mention in chapter 3.5 and higher fineness of cement. According to Moghaddam, et al., (2019) fly ash cement is normally having high fineness. Lower specific gravity indicates that under same weight of cement, higher volume of cement is needed, and high fineness indicate that the cement is fine and finer particle of cement will have larger total surface area. Hence, with constant amount of w/c ratio in design mix, more water is needed to wet the cement particle for PFA 32.5N and result in low workability of fresh concrete. The mixing condition of PFA 32.5N is shown in Figure 5.4, it can be seen that the fresh concrete mix forms into clumps or balls, indicating poor mixing and a lack of homogeneity. Low workability of concrete makes it difficult to blend well together, resulting in a non-uniform consistency that is difficult to work with.

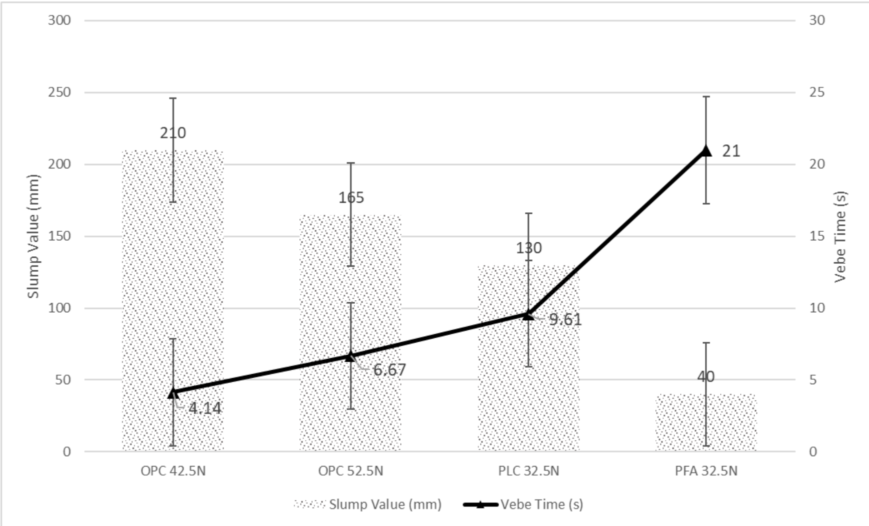

Figure 5.1: Result of Slump Value and Vebe Time.

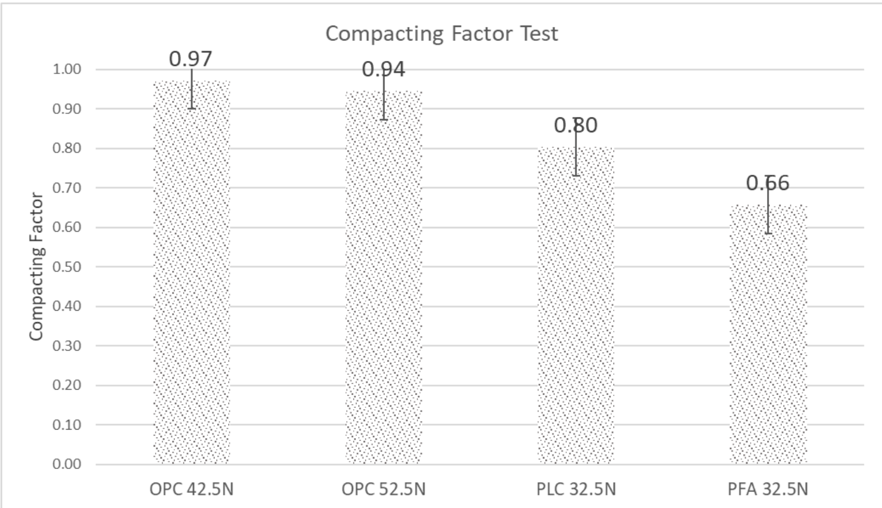

Figure 5.2: Result of Compacting Factor.

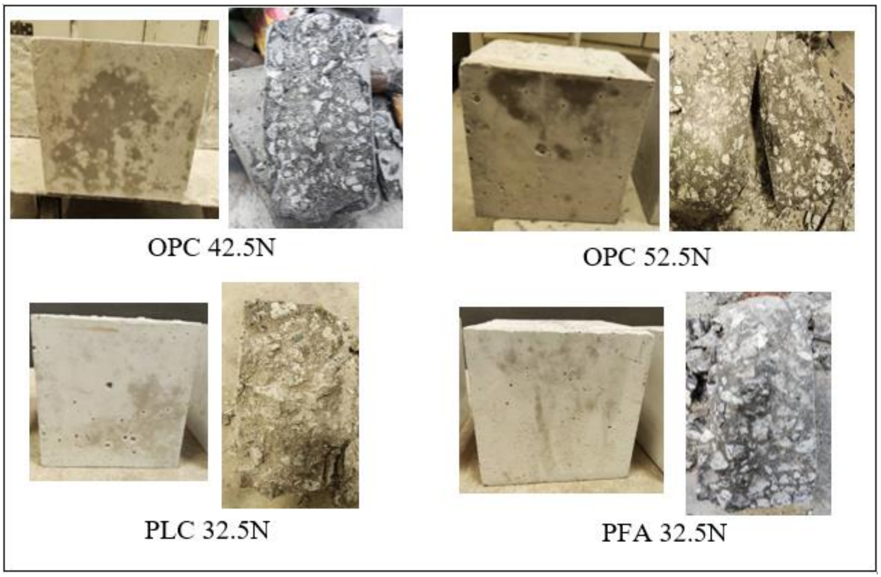

Figure 5.3: Surface and Segregation Condition of Concrete.

Figure 5.4: Mixing Condition of PFA 32.5N.

5.4 Density

Fresh density and hardened density were assessed in the Actual mix. Figure 5.5 illustrate the fresh and hardened density of OPC 42.5N, OPC 52.5N, PLC 32.5N, and PFA 32.5N.

From figure 5.5, it is observed that the hardened density of OPC 52.5N is the highest and follow by OPC 42.5N, PLC 32.5N and PFA 32.5N. The density of hardened concrete is higher than the fresh density, which the result is similar with Gupta, et al., (2018), except for PLC 32.5N. In overall, the density of concretes does not experience significant changes from fresh state to hardened state.

The result shows that the slight development of density from fresh state to hardened state. It shows that OPC 42.5N experience highest density growth and followed by PFA 32.5N, and OPC 52.5N which are 1.83%, 0.76% and 0.08% growth. The growth of density may be due to the forming of denser component such as calcium silicate hydrate (CSH) gel in the concrete that binds the aggregate particles together during hydration process, when the original component or the void in concrete is replaced by the denser CSH gel, the concrete density increase and the higher the density growth, the higher the percentage of denser CSH gel form in the concrete.

For PLC 32.5N, the fresh density is slightly higher than hardened density. This may be due to the expel of air and excess water during the concrete cures and hardens, leading to a slight reduction in density in the hardened state (Kovler & Roussel, 2011).

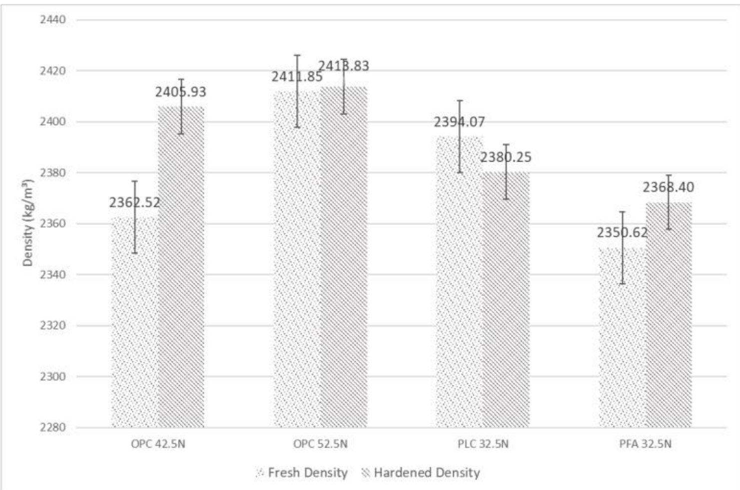

Figure 5.5: Result of Fresh and Hardened Density.

5.5 Initial Setting Time

The initial setting time of 4 types of concrete sample is illustrate in Figure 5.6. The concrete achieves initial set when the penetration resistance reaches 500 psi which is represented by the red horizontal line in Figure 5.6. The test result is tabulated in Appendix B-4.

The results shows that the initial setting time of OPC 42.5N, OPC 52.5N, PLC 32.5N, and PFA 32.5N are 170 minutes, 105 minutes, 100 minutes, and 55 minutes. From the result, it is noticeable that OPC 42.5N have the longest initial setting time, OPC 52.5N and PLC 32.5N have similar initial setting time and PFA 32.5N achieved initial set the fastest.

Due to the high slump value of fresh cement for OPC 42.5N which caused by the superplasticiser as mention in Chapter 5.3, the fresh concrete is considered too wet and therefore required longer time to reach initial set. Likewise, for PFA 32.5N, the dryness of the fresh concrete contributes to its penetration resistance, allowing it to achieve the initial set faster. This is facilitated by the finer cement particles, which have a larger surface area exposed to water, thereby promoting faster hydration and a quicker setting time. On the other hand, from the composition of C_3A and C_3S which contributing to the initial setting time shows in chapter 3.3.1, OPC 52.5N shows higher composition than OPC 42.5N and this explained why OPC 52.5N set faster than OPC 42.5N. Although OPC 52.5N has the highest content of C_3A and C_3S in the cement, the PCC cement still having a shorter setting time, this may be due to the effect of limestones and fly ashes that may promote the reaction of C_3A and C_3S in initial hydration. Hence, in overall, PCC reach initial set faster than OPC.

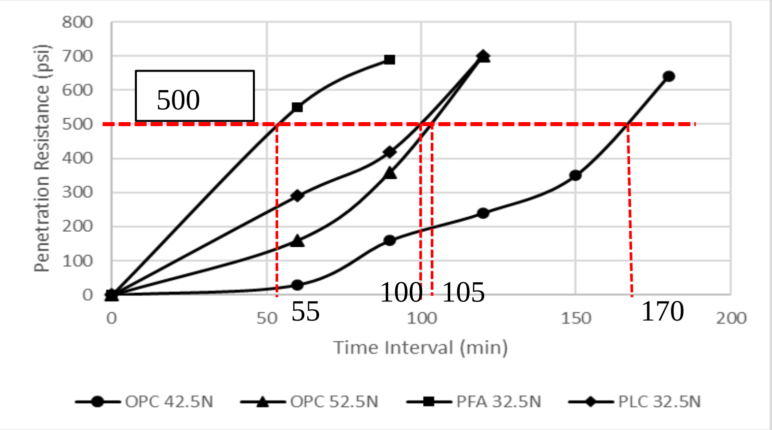

Figure 5.6: Result of Initial Setting Time Test

5.6 Hardened Properties

The compressive cube and cylinder strength were performed in the actual mix of this study. The results of compressive cube strength and cylinder strength are tabulated in Appendix B-5 and Appendix B-6 respectively.

5.6.1 Compressive Strength

There were two compressive strength tests carried out in this study which include the compressive cube strength test and compressive cylinder strength test. The compressive cube and cylinder strength of concrete at 7 days, 28 days and 56 days for four different concrete mixes: OPC 42.5N, OPC 52.5N, PLC 32.5N and PFA 32.5N are shown in Figure 5.7 and Figure 5.8 respectively.

From the result, it shows that OPC 42.5 achieved highest compressive strength, follow by OPC 52.5N, PLC 32.5N and PFA 32.5N at 7 days and 28 days. At 56 days, the strength of OPC 52.5N become slightly higher than the strength of OPC 42.5, meanwhile, PFA 32.5N was still higher than PLC 32.5N and lower than OPC 42.5N and OPC 52.5N. Both OPC 42.5N and OPC 52.5N can achieve strengths of 71 MPa and 69 MPa, respectively, at 28 days, meeting the study's objective of 67 MPa at 28 days. They both demonstrate similar results at 56 days, achieving a strength of 72 MPa. For PLC 32.5N and PFA 32.5N, both mixes do not achieve the minimum designed strength. Both OPC are capable to achieve the highest strength indicate that more CSH gel is form for both mixes compared to PLC 32.5N and PFA 32.5N. From the composition of C_3S and C_3A mention in chapter 3.3.1, it shows that the C_3S and C_3A of OPC cement is higher than PCC cement, so it is expected that the strength of OPC 42.5N and OPC 52.2N will be higher than PLC 32.5N and PFA 32.5N, which the result of the strength is match with the expectation.

Analysing the graph, we can see a trend of increasing strength for all concrete mixes as the curing age progresses. This indicates that the development of concrete strength over time. It can be seen that, a sharper rise in strength in the earlier stages (from 0 days to 7 days) as hydration reactions between cement and water rapidly form strong bonds. The concrete mixes achieved strengths at 7 days that were 99.41%, 93.40%, 91.21%, and 85.27% of their respective 28 days strengths for OPC 42.5N, OPC 52.5N, PLC 32.5N, and PFA 32.5N. These values surpassed the theoretical expectation of 66.67%. This initial jump may be due to the high content of C_3S and C_3A in the cement, however the other reason to this high initial strength may be due to the superplasticiser added in the concrete mix. Superplasticisers can help in dispersing cement particles more uniformly throughout the mix. This results in better hydration as each particle is effectively exposed to water, leading to a more rapid initial strength gain. It can also improve the effectiveness of curing by ensuring that the concrete remains well-compacted and free from voids, result in achieving higher early-age strengths (Xun, et al., 2020).

The concrete mix with OPC (OPC 42.5N and OPC 52.5N) show higher growth of early strength compared to PCC mixes (PLC 32.5N and PFA 32.5N). This may be due to higher C_3S and C_3A content in the OPC, while PCC contains a blend of clinker and supplementary cementitious materials (SCMs) like fly ash or limestone, these SCMs contribute to long-term strength but react slower than clinker (Basar, et al., 2023). On the other hand, the later stages (between 28 and 56 days) might show a more gradual increase as the hydration process continues to fill the spaces between cement particles. Form the result, it can be seen that the concretes have growth the strength of 0.73%, 5.24%, 8.70% and 9.89% from 28 days to 56 days for OPC 42.5N, OPC 52.5N, PLC 32.5N, and PFA 32.5N, respectively. The strength of OPC 42.5N just experiences slight growth compared to OPC 52.5N which may be due to the higher C_2S (component that contributing later strength) content in OPC 52.5N which shows in chapter 3.3.1. For PCC mixes, both PLC 32.5N and PFA 32.5N show greater growth of strength than OPC mixes which due to the pozzolanic reaction in PCC mixes that develop the later strength of concrete. It is noticeable that PFA 32.5N experience higher later strength growth compared to PLC 32.5N.

On top of that, for concrete compressive cylinder strength, the test is to ensure the concretes to achieve the cylinder strength of 55MPa at 28 days in objective of this study. From Figure 5.8, it can be concluded that only OPC 42.5N achieve the desired cylinder strength of minimum 55 MPa which is 66.91 MPa. For OPC 52.5N, the cylinder strength is 1.60% slightly lower than the desired strength. Both PLC 32.5N and PFA 32.5N do not reach the desired strength of minimum 55 MPa.

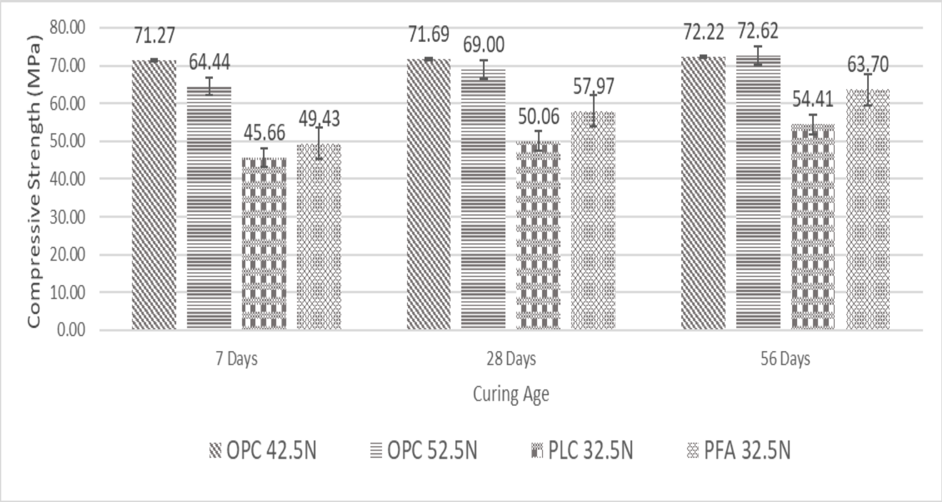

Figure 5.7: Result of Compressive Cube Strength.

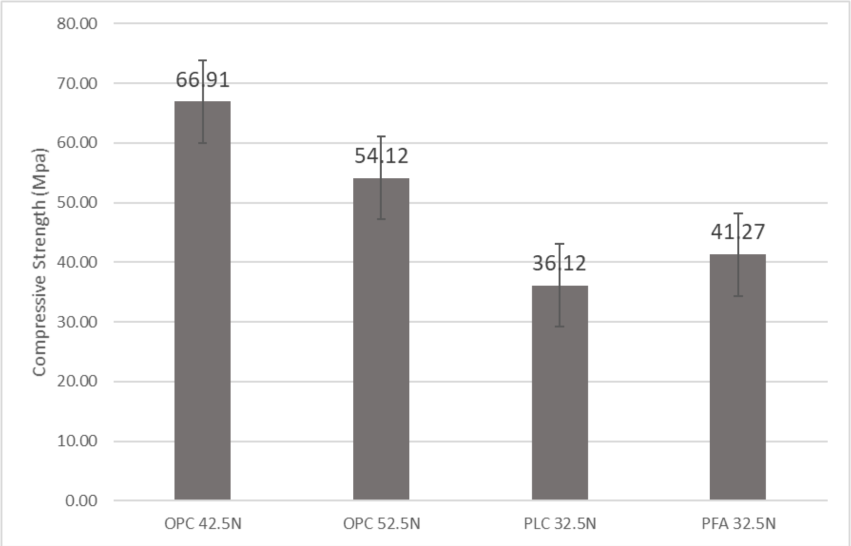

Figure 5.8: Result of Compressive Cylinder Strength at 28 days.

5.7 Concrete Temperature Test

The concrete temperature test was carried out, once the mixing of concrete was done. The test will be carried out until the concrete reaches its maximum temperature and started to drop which is around 9 to 10 hours in this study. The graph plotted for the concrete temperature over the time interval for OPC 42.5N, OPC 52.5N, PLC 32.5N and PFA 32.5N is shown in Figure 5.9. The result of temperature test is tabulated in Table 5.2.

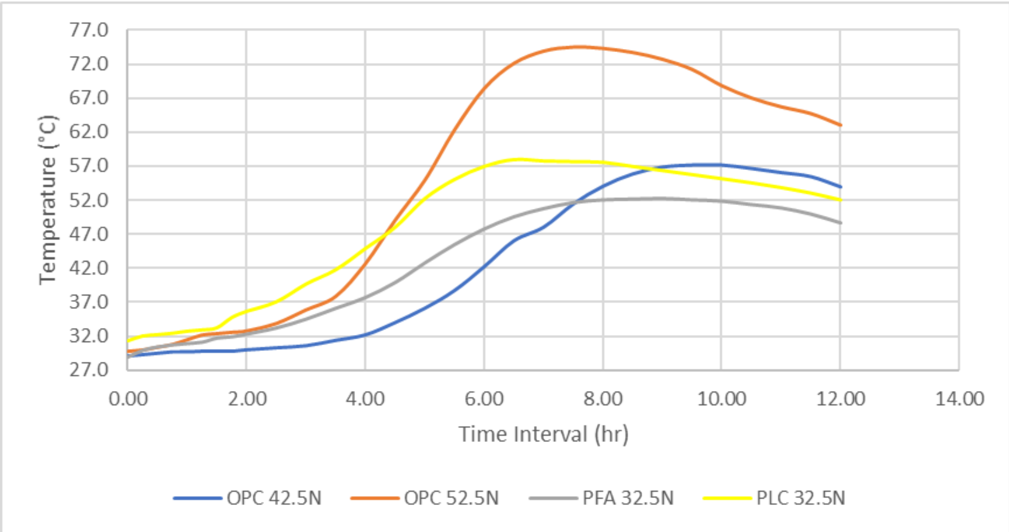

Figure 5.9: Concrete Temperature over Time Interval.

Table 5.2: Result of Concrete Temperature Test.

Cement	Time Taken to Reach Maximum Temperature (hr)	Maximum Temperature (°C)
OPC 42.5N	9.5	57.1
OPC 52.5N	7.5	74.5
PLC 32.5N	6.5	57.9
PFA 32.5N	9.0	52.3

From Figure 5.9 and Table 5.2 it can be seen that OPC 52.5N achieve the highest peak temperature which is significantly higher that than other 3 types of cement. The peak temperatures of OPC 42.5N and PLC 32.5N are quite similar where OPC 42.5N is relatively lower than PLC 32.5N. PFA 32.5N achieve the lowest peak temperature. Higher peak temperature may be due to higher content of heat contributing compound (C_3A and C_3S) in the cement which mean OPC 52.5N may content higher content of C_3A and C_3S. The result is match with the expectation result from the composition of C_3A and C_3S mention in chapter 3.3.1 where OPC 52.2N has highest content, follow by OPC 42.5N, PLC 32.5N and PFA 32.5N.

Figure 5.9 suggest that PLC 32.5N has the fastest rate of temperature development. It reaches its peak temperature in just 6.5 hours indicating a steepest initial rise compared to the other cements. This could be due to the presence of limestone in PLC 32.5N, which can contribute to a faster hydration reaction at early stages. Although OPC 42.5N and PFA 32.5N exhibit a similar time taken to achieve the peak temperature which is 9.5 hours and 9.0 hours respectively, OPC 42.5 has higher peak temperature so it has steeper initial rise of temperature compare to PFA 32.5N. It can be seen that, the temperature does not experience an obvious increment at the beginning of the test, the growth become steeper after around 4 hours. OPC 52.5N takes 7.5 hours to reaches the peak temperature, however since its peak temperature is significantly higher than the others type of cement, the rate of temperature growth is the highest. The temperature experience higher rate of growing after around 3.5 hours.

Other than the chemical composition of cement, OPC 52.5N are capable to reach such high temperature maybe due to the fineness of the cement. The finer cement has larger total surface area which enable the cement particle to react well with water and hence have higher rate of hydration and emit more heat (Kosmatka & Farny, 2018). OPC 52.5N has higher fineness compared to OPC 42.5N, therefore OPC 52.2N can achieve highest peak temperature in short time. Similar result shows in (Kosmatka & Farny, 2018), where Type I OPC cement can release more heat compared to PCC cement. Besides, although OPC 52.5N can reach such high peak temperature in short time, it may result in negative effect on the long-term durability of the concrete as the concrete may experience thermal expansion and shrinkage in short time and result in cracking in the microstructure of concrete.

5.8 XRD for Cement Paste

The XRD test for hardened cement paste was carried out after curing for 4 days. The result of XRD for cement paste of OPC 42.5N, OPC 52.5N, PLC 32.5N and PFA 32.5N is illustrated in Appendix A-6, Appendix A-7, Appendix A-8, and Appendix A-9 respectively. The result of XRD for cement paste is tabulated in Table 5.3.

Table 5.3: Chemical Composition of Hydrated Product by XRD Test.

Chemical Composition	**Percentage (%)**			
	OPC 42.5N	**OPC 52.5N**	**PLC 32.5N**	**PFA 32.5N**
C-S-H	21	22.4	15.8	18
Portlandite	19	21.4	20.8	16
Alite	13	16.3	10.9	12
Belite	10	11.2	11.9	14
Celite	15	11.2	12.9	12
Brownmillerite	9	7.1	5.0	2
Gypsum	3	5.1		
Calcite	10	5.1	14.9	10
Silicon Dioxide				16
Dolomite			7.9	

From Table 5.3, it can be observed that, the CSH content is highest for OPC 52.5N, followed by OPC 42.5N, PFA 32.5N, and PLC 32.5. OPC 52.5N shows highest content of CSH gel may indicate it has highest strength, and this is matching with the actual result from the compressive strength test in chapter 5.6.1 as the strength of OPC 52.5N is the highest. From the XRD result, the sequence of strength for OPC 52.5N, OPC 42.5N, PFA 32.5N, and PLC 32.5 in chapter 5.6.1 is matched with the content of CSH of each concrete in XRD test. Higher content of CSH gel form in the hydrated product indicate higher strength of concrete, however the strength can also be affected by other factor such as the air void and uniformity of hydrated product in concrete. The XRD result is only done for cement paste that cure for 4 days, so it may not represent the result at later age.

5.9 Summary

In summary, the for the fresh properties of OPC 42.5N has highest workability, follow by OPC 52.5N, PLC 32.5N and PFA 32.5N. In term of hardened density, OPC 52.5N is the highest and follow by OPC 42.5N, PLC 32.5N and PFA 32.5N. in addition, for the initial setting time, PFA 32.5N achieve initial set the fastest, follow by PLC 32.5N, OPC 52.5N and OPC 42.5N. As for the compressive strength of concrete, OPC 42.5N and OPC 32.5N are capable to achieve the desired strength of 67 MPa at 28 days, where OPC 42.5N get higher strength than OPC 52.5 at 7 days and 28 days, but OPC 52.5N achieves higher strength than OPC 32.5N at 56 days. For PLC 32.5N and PFA 32.5N, both concrete do not achieve the desired strength, and the strength of PFA 32.5N is higher than PLC 32.5N. For concrete temperature test, PLC 32.5N can reach its maximum temperature in the shortest time, followed by OPC 52.5N, PFA 32.5N, and OPC 42.5N cement. However, OPC 52.5N can reach the highest temperature, which is significantly higher than the others, in a short time after mixing, followed by PLC 32.5N, OPC 42.5N, and PFA 32.5N.

On top of that, XRD test for cement paste is carried out to justified the result of the tests.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

After conducting numerous tests to assess the properties of the concrete prepared with various type of cement, conclusions that match to the study's objective are made.

The first objective of this study is to achieve the design strength of C55/67 concrete at 28-day prepares with various types of cement. This objective is only achieved by OPC 42.5N and OPC 52.5N. Among four different cement use in this study, there are only OPC cement which is OPC 42.5N and OPC 52.5N achieve the desired strength of minimum 67 MPa at 28 days. The PCC cement which are PLC 32.5N and PFA 32.5N are both do not achieve the first objective.

The second objective is to study the fresh and mechanical properties of C55/67 concrete prepares with various types of cement. For the fresh properties of concrete, OPC 42.5N exhibits the highest workability and compacting factor compared to other cement types, followed by OPC 52.5N, PLC 32.5N, and PFA 32.5N. OPC 42.5N and OPC 52.5N are both capable of reaching 71 and 69 MPa, respectively, at 28 days. They both demonstrate similar results at 56 days, achieving a strength of 72 MPa. The strength of PLC 32.5N and PFA 32.5N at 28 days and 56 days are 49 MPa, 57 MPa, 54 MPa and 63 MPa respectively which do not pass the minimum desired strength.

The last objective is to study the concrete temperature of C55/67 concrete prepared with various types of cement. PLC 32.5N can reach its peak temperature in the shortest time, followed by OPC 52.5N, PFA 32.5N, and OPC 42.5N, which take 6.5, 7.5, 9.0, and 9.5 hours respectively. However, OPC 52.5N can reach its peak temperature, which is significantly higher than the others, in a short time after mixing, followed by PLC 32.5N, OPC 42.5N, and PFA 32.5N, with temperatures of 74.5°C, 57.9°C, 57.1°C, and 52.3°C respectively.

6.2 Recommendations for Future Work

The following recommendations are suggested to improve study outcome and enhance the viability of data obtained to improve the future studies.

(i) Study the strength properties for earlier curing age which is at 1 day or 3 days to get a clearer picture of the initial strength development and validate the possibility of a steeper rise in the early stages.

(ii) Study the long-term strength after 56 days of curing as the development of strength after 56 days may still continue and develop higher long-term strength which will be beneficial to the structure.

(iii) Study the durability properties of concrete prepared with various type of cement to find out the effect by the concrete temperature.

(iv) Study on the concrete properties by using different curing condition such as wet curing, dry curing or steam curing and compared the difference between various type of cement.

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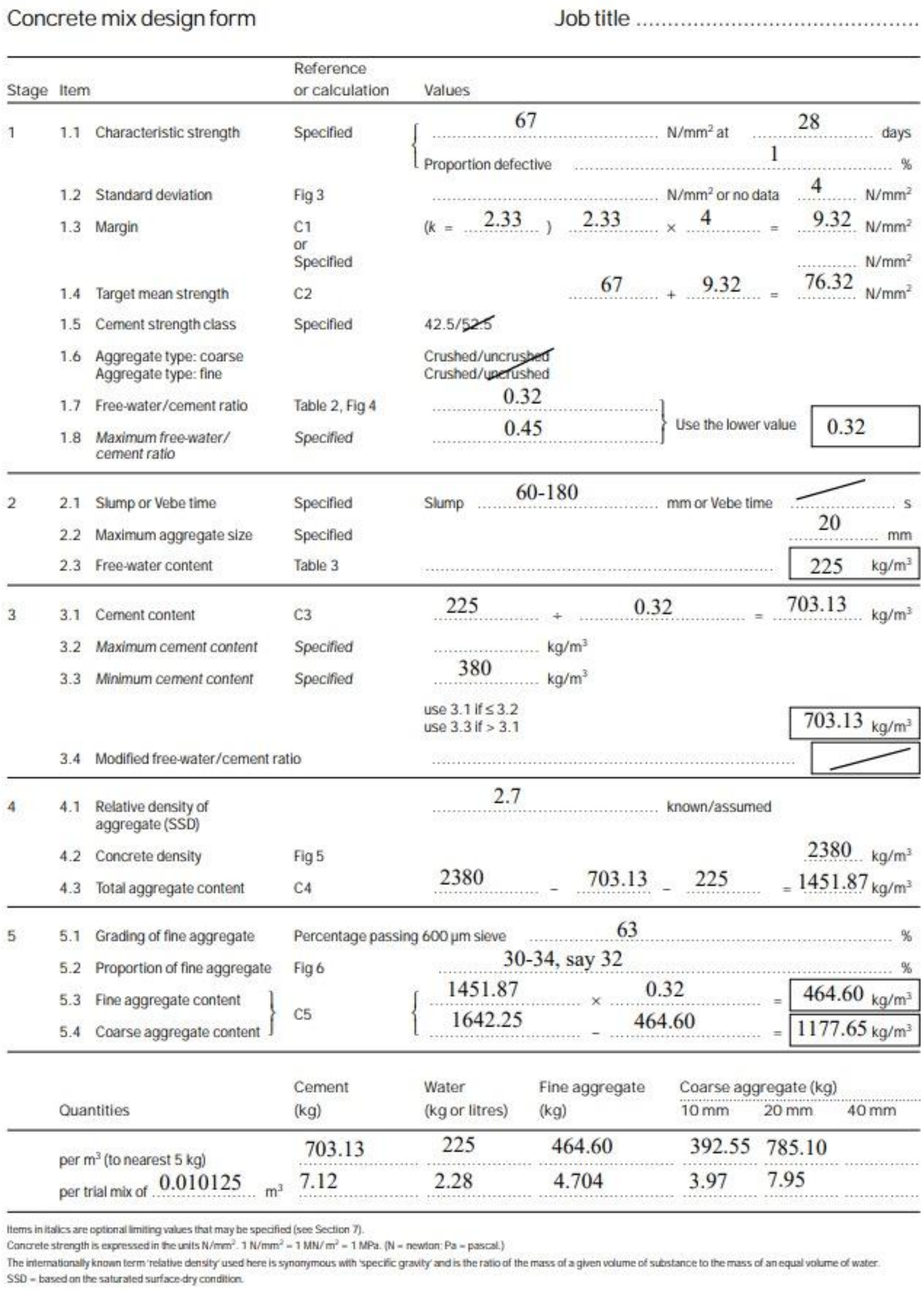
APPENDICES

Appendix A: Figures



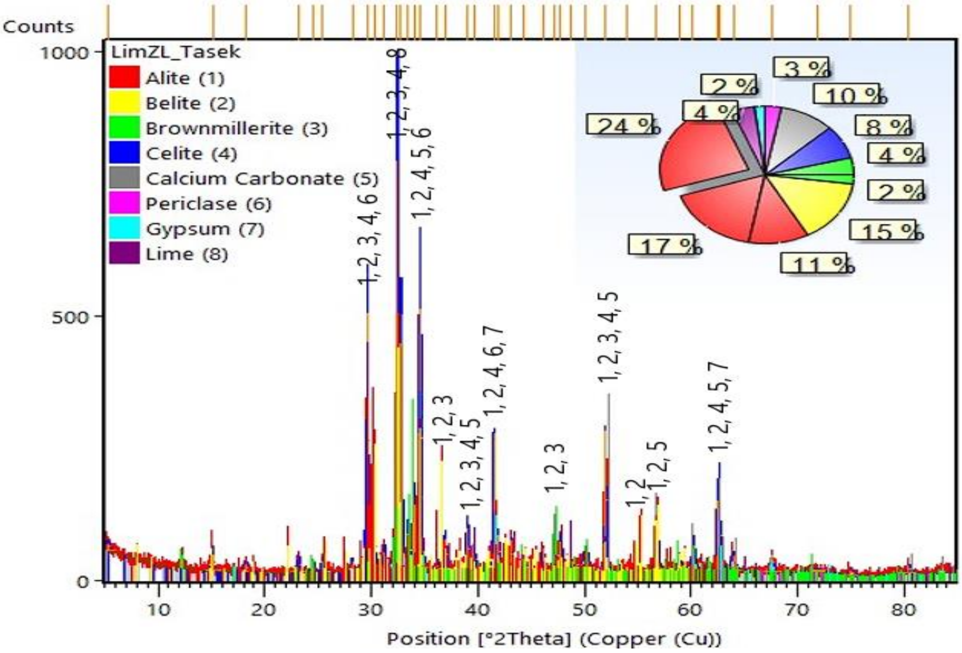
Concrete mix design form   Job title ....

Stage	Item		Reference or calculation	Values
1	1.1	Characteristic strength	Specified	67 N/mm² at 28 days; Proportion defective 1 %
	1.2	Standard deviation	Fig 3	.... N/mm² or no data 4 N/mm²
	1.3	Margin	C1 or Specified	(k = 2.33) 2.33 × 4 = 9.32 N/mm²; .... N/mm²
	1.4	Target mean strength	C2	67 + 9.32 = 76.32 N/mm²
	1.5	Cement strength class	Specified	42.5/~~52.5~~
	1.6	Aggregate type: coarse Aggregate type: fine		Crushed/~~uncrushed~~ Crushed/~~uncrushed~~
	1.7	Free-water/cement ratio	Table 2, Fig 4	0.32 } Use the lower value 0.32
	1.8	*Maximum free-water/ cement ratio*	*Specified*	0.45 }
2	2.1	Slump or Vebe time	Specified	Slump 60-180 mm or Vebe time — s
	2.2	Maximum aggregate size	Specified	20 mm
	2.3	Free-water content	Table 3	225 kg/m³
3	3.1	Cement content	C3	225 ÷ 0.32 = 703.13 kg/m³
	3.2	*Maximum cement content*	*Specified*	.... kg/m³
	3.3	*Minimum cement content*	*Specified*	380 kg/m³
				use 3.1 if ≤ 3.2 use 3.3 if > 3.1 — 703.13 kg/m³
	3.4	Modified free-water/cement ratio		—
4	4.1	Relative density of aggregate (SSD)		2.7 known/assumed
	4.2	Concrete density	Fig 5	2380 kg/m³
	4.3	Total aggregate content	C4	2380 − 703.13 − 225 = 1451.87 kg/m³
5	5.1	Grading of fine aggregate	Percentage passing 600 µm sieve	63 %
	5.2	Proportion of fine aggregate	Fig 6	30-34, say 32 %
	5.3	Fine aggregate content	C5	1451.87 × 0.32 = 464.60 kg/m³
	5.4	Coarse aggregate content	C5	1642.25 − 464.60 = 1177.65 kg/m³

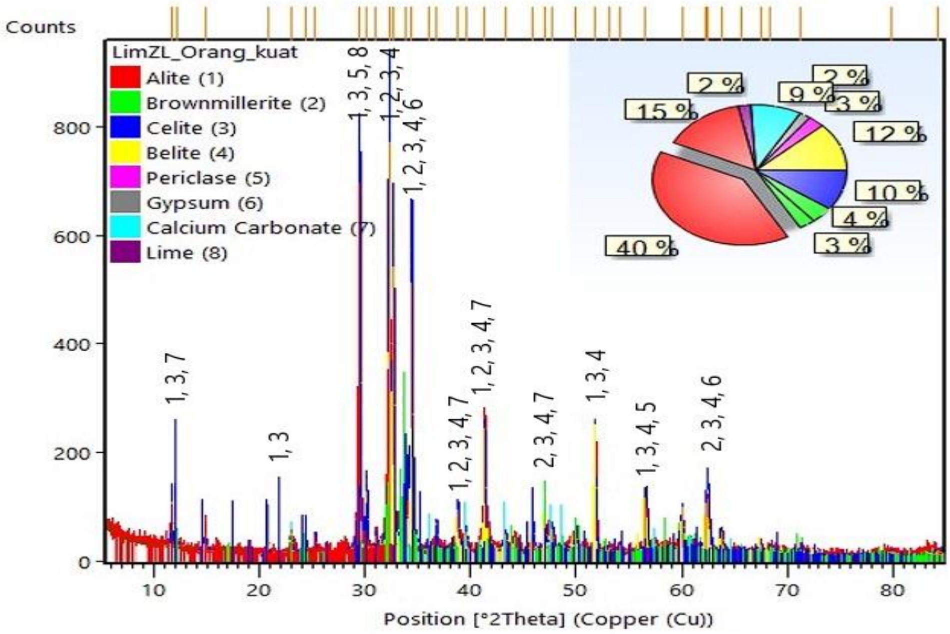
Quantities	Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg) 10 mm	20 mm	40 mm
per m³ (to nearest 5 kg)	703.13	225	464.60	392.55	785.10	
per trial mix of 0.010125 m³	7.12	2.28	4.704	3.97	7.95	

Items in italics are optional limiting values that may be specified (see Section 7).
Concrete strength is expressed in the units N/mm². 1 N/mm² = 1 MN/m² = 1 MPa. (N = newton; Pa = pascal.)
The internationally known term 'relative density' used here is synonymous with 'specific gravity' and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.
SSD = based on the saturated surface-dry condition.

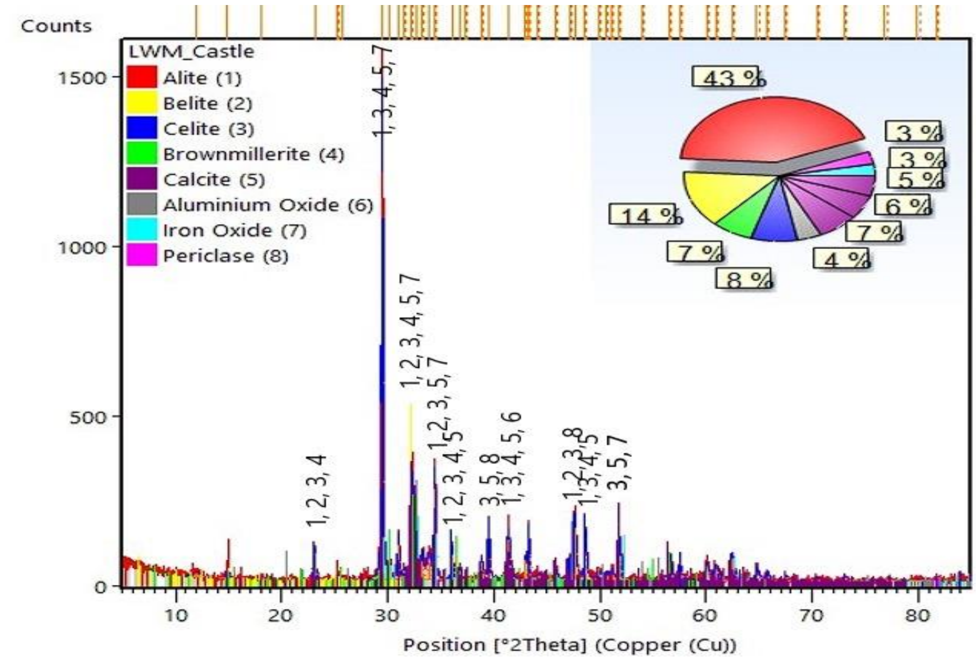
Appendix A- 1: Design of Normal Concrete Mix Proportion.



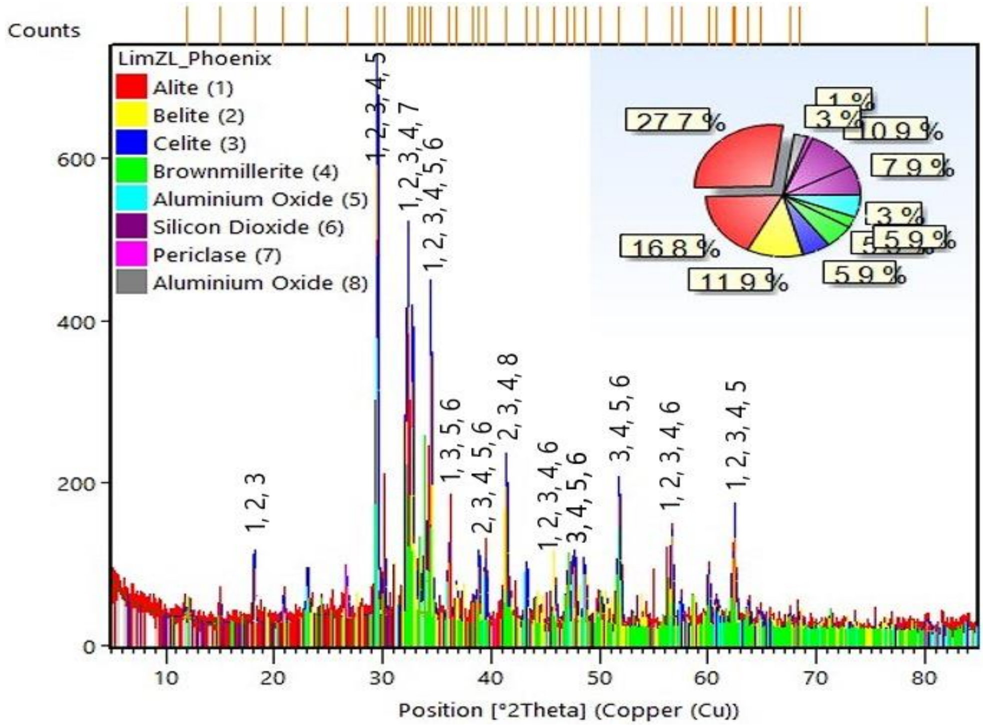
Appendix A- 2: XRD Analysis of OPC 42.5N Cement.



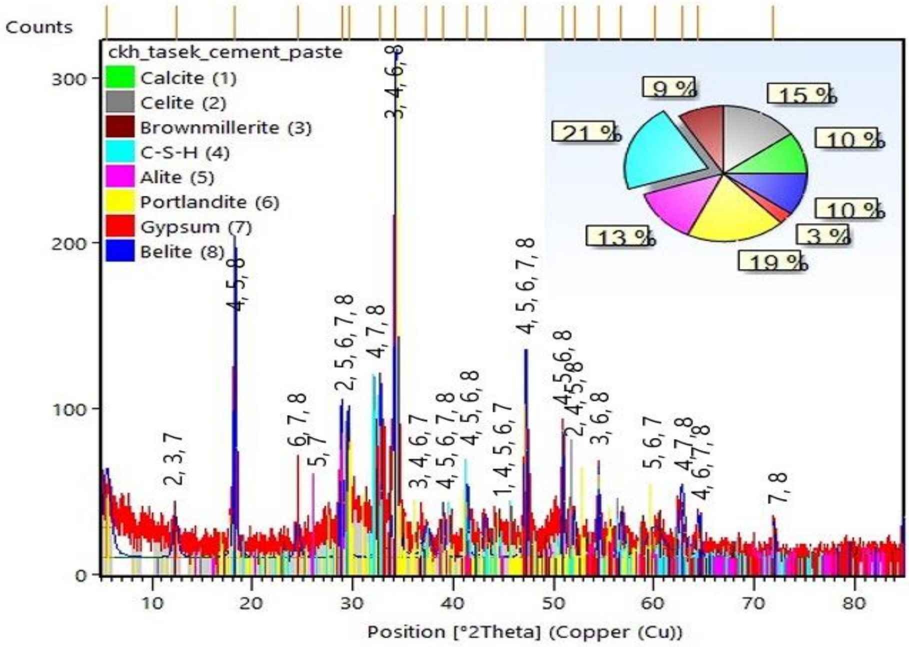
Appendix A- 3: XRD Analysis of OPC 52.5NN Cement.



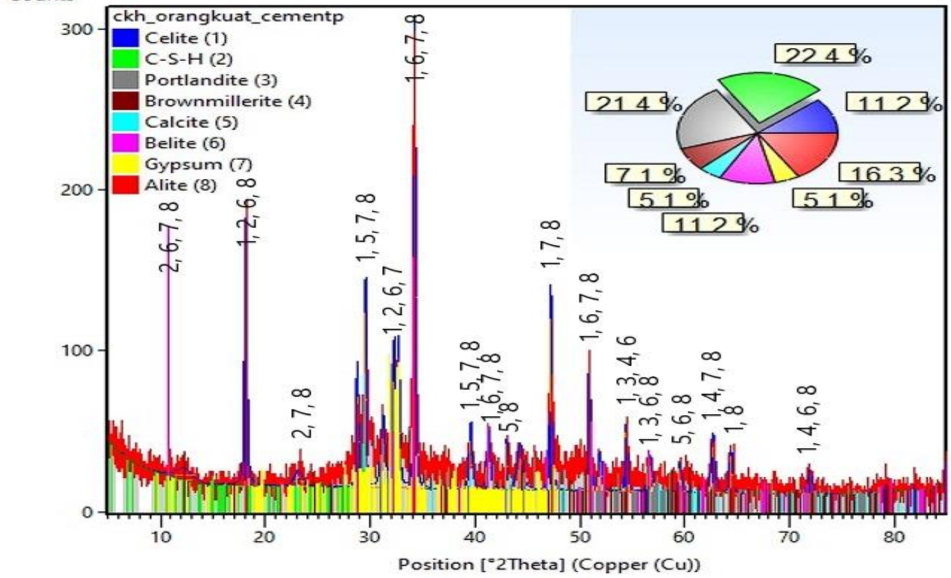
Appendix A- 4: XRD Analysis of PLC 32.5N Cement.



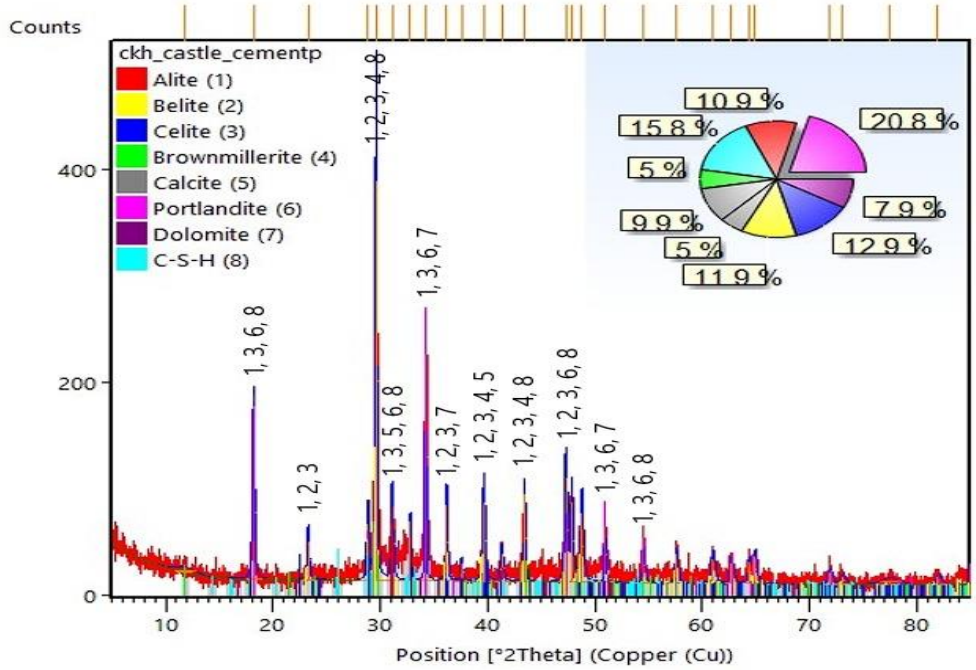
Appendix A- 5: XRD Analysis of PFA 32.5N Cement.



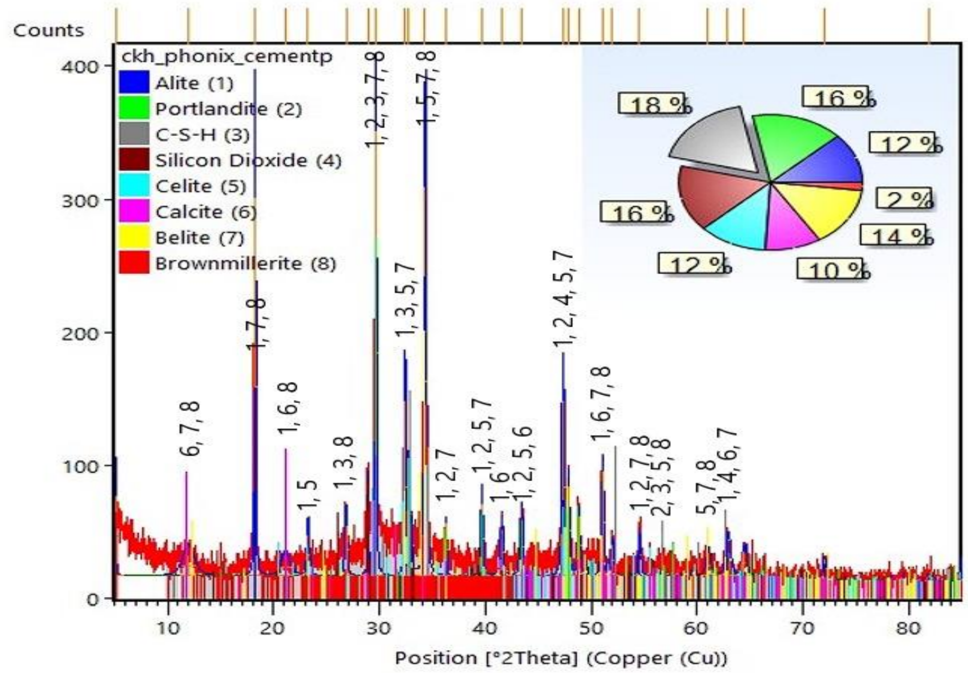
Appendix A- 6: XRD Result of OPC 42.5N Cement Paste.



Appendix A- 7: XRD Result of OPC 52.5N Cement Paste.



Appendix A- 8: XRD Result of PLC 32.5N Cement Paste.



Appendix A- 9: XRD Result of PFA 32.5N Cement Paste.

Appendix B: Tables

Appendix B- 1: Sieve Analysis of Fine Aggregate.

Sieve Size (mm)	Weight (g)				Cumulative Percentage (%)	
	Empty Sieve	Aggregate Retained + Sieve	Aggregate Retained on Each Sieve	Aggregate Retained on Each Sieve (%)	Coarser	Finer
4.75	489.40	490.45	1.05	0.21	0.21	99.79
2.36	468.75	473.15	4.40	0.88	1.09	98.91
1.18	371.40	416.70	45.30	9.06	10.15	89.85
0.6	380.15	518.15	138.00	27.60	37.75	62.25
0.3	366.45	500.65	134.20	26.84	64.59	35.41
0.15	365.65	518.65	153.00	30.60	95.19	4.81
Pan	245.75	269.80	24.05	4.81	100.00	0.00
Total			500.00	100.00		
Fineness Modulus				2.09		

Appendix B- 2: Sieve Analysis of Coarse Aggregate.

Sieve Size (mm)	Weight (g)				Cumulative Percentage (%)	
	Empty Sieve	Aggregate Retained + Sieve	Aggregate Retained on Each Sieve	Aggregate Retained on Each Sieve (%)	Coarser	Finer
20.00	391.30	391.45	0.15	0.02	0.02	99.98
14.00	397.95	854.65	456.70	45.74	45.76	54.24
10.00	454.55	810.80	356.25	35.68	81.44	18.56
4.75	489.30	669.45	180.15	18.04	99.48	0.52
pan	245.00	250.20	5.20	0.52	100.00	0.00
Total			998.45	100.00		
Fineness Modulus				7.27		

Appendix B- 3: Compressive Strength of Trial Mix for OPC 42.5N.

W/C Ratio	SP Dosage (%)	Compressive Strength (MPa)					
		7 days			28 days		
		1	2	3	1	2	3
0.34	**0.17**	50.61	48.75	48.82	59.66	63.29	56.27
0.32	**0.17**	56.37	55.63	54.31	63.20	59.92	61.31
	0.20	54.97	53.03	52.54	55.11	55.74	57.85
0.30	**0.15**	56.32	52.96	54.76	61.55	60.63	62.25
	0.20	62.43	60.76	60.43	65.22	65.13	65.82
0.28	**0.23**	60.22	60.55	62.78	66.5	64.94	65.27
0.26	**0.30**	65.86	65.69	64.92	67.54	70.44	67.89
	0.35	63.46	63.01	65.30	67.75	68.70	67.28

Appendix B- 4: Result of Initial Setting Time Test.

Time Interval (min)	Penetration Resistance (psi)			
	OPC 42.5N	OPC 52.5N	PLC 32.5N	PFA 32.5N
0	0	0	0	0
60	30	160	290	550
90	160	360	420	690
120	240	>700	>700	
150	350			
180	640			

Appendix B- 5: Result of Compressive Cube Strength for Actual Mix.

Concrete Sample	**Compressive Cube Strength (MPa)**								
	Curing Age (days)								
	7			**28**			**56**		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
OPC 42.5N	70.48	71.46	71.88	71.91	70.14	73.03	72.7	71.63	72.33
OPC 52.5N	63.66	62.76	66.91	72.57	68.26	66.17	71.99	76.29	69.57
PLC 32.5N	45.56	43.87	47.54	52.19	49.42	48.56	54.36	54.78	54.09
PFA 32.5N	51.06	47.37	49.87	56.99	60.42	56.5	63.44	64.28	63.39

Appendix B- 6: Result of Compressive Cylinder Strength for Actual Mix.

Concrete Sample	**Compressive Cylinder Strength at 28 days (MPa)**		
	1	**2**	**3**
OPC 42.5N	70.29	62.21	68.22
OPC 52.5N	53.48	58.82	50.06
PLC 32.5N	41.82	36.42	30.11
PFA 32.5N	39.92	42.26	41.63