AN EXPERIMENTAL INVESTIGATION EXPLORING THE EFFECTS OF DELAYED CASTING ON GRADE 30 CONCRETE SLUMP BEHAVIOR AND COMPRESSIVE STRENGTH SUBSEQUENT TO RE-DOSING WITH LOW-RANGE SUPERPLASTICIZER

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

Lee Kong Chian Faculty of Engineering and Science
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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 **"AN EXPERIMENTAL INVESTIGATION EXPLORING THE EFFECTS OF DELAYED CASTING ON GRADE 30 CONCRETE SLUMP BEHAVIOR AND COMPRESSIVE STRENGTH SUBSEQUENT TO RE-DOSING WITH LOW-RANGE SUPERPLASTICIZER"** was prepared by **CHAN MAN YOU** 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

Chemical admixtures are vital in concrete construction for enhancing workability and strength. However, delayed casting can reduce slump below desired levels. While adding water to restore slump is common on-site, but it will compromises compressive strength. However, research on re-dosing with superplasticizer after delayed casting is limited. This research investigates the impact of delayed casting on Grade 30 concrete's slump behavior and compressive strength, focusing on the effects of re-dosing with a low-range superplasticizer, MasterGlenium Ace 8333, and the implications of water addition. The superplasticizer dosages used ranged from 0.1% to 0.7%, with 0.1% increments. The tests conducted were slump, Vebe time, compacting factor, fresh density, air content, hardened density, and compressive strength. Results show that delayed casting reduced the 7 and 28 days compressive strengths by approximately 26% and 24% compared to the control mix. When water was added after delayed casting, compressive strength further decreased by about 4% at both 7 and 28 days. Re-dosing with a superplasticizer, particularly at a dosage of 0.2%, successfully restored the original slump and improved the 7 and 28 days compressive strengths, achieving the required strength. However, as the superplasticizer dosage increased, slump values continued to rise, peaking at 220 mm for a 0.7% dosage, while the initial slump for delayed casting was only 48 mm, representing a significant improvement. This study highlights the importance of optimizing superplasticizer dosage to enhance concrete performance under delayed casting conditions, emphasizing careful management to maintain concrete quality in construction scenarios with frequent delays.

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LIST OF SYMBOLS / ABBREVIATIONS

A	air content, %
A_c	maximum load at failure, N
D	fresh density, kg/m^3
F	cross-sectional area of specimen on which the compressive force acts, m^2
f_c	compressive strength, MPa
H_1	average depth of concrete in the vertical section of box, mm
H_2	average depth of concrete at the end of the horizontal section of box, mm
T	theoretical density of concrete computed on an air free basis, kg/m^3
V_m	volume of cylinder, m^3
W_c	weight of cylinder filled with concrete, kg
W_e	weight of empty cylinder, kg
W_f	weight of fully compacted concrete, kg
W_p	weight of partially compacted concrete, kg

FM	fineness modulus
PCE	polycarboxylic ether
PL	passing ability ratio
SP	superplasticizer
TPR	total percentage retained from the biggest size observed to and including sieve size 150 µm.
w/c	water-cement ratio

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Concrete is one of the most widely used construction materials globally due to its versatility, strength, and durability (Mehta & Monteiro, 2014). However, its performance is significantly influenced by the materials used and the process of mixing, casting, and curing. In particular, the workability of fresh concrete often measured by its slump behavior and its compressive strength after curing are key indicators of the quality of concrete (Neville, 2011). These properties are affected by various factors, including time delays in the casting process, the use of admixtures, and environmental conditions. One of the critical challenges in concrete construction is maintaining the desired workability during such delays which can be crucial for large-scale construction projects where concrete may not always be poured immediately after mixing (Kosmatka & Wilson, 2016).

The introduction of superplasticizers, particularly low-range superplasticizers (LRSP) has provided an effective solution for enhancing the workability of concrete without significantly altering its water-cement ratio (Ramachandran, 2001). These chemical admixtures work by dispersing cement particles more effectively, thus increasing the fluidity of the concrete mix (Lei & Plank, 2011). However, delays between the mixing and casting of concrete are inevitable due to logistical or operational challenges in practical situations. During such delays, the workability of concrete can decrease as it begins to set. This is where the practice of re-dosing with superplasticizers becomes relevant, aiming to restore the slump and extend the workability window.

This study focuses on Grade 30 concrete, a commonly used grade in construction that is characterized by a specified compressive strength of 30 MPa after 28 days of curing (ACI Committee, 2005). The experimental investigation seeks to understand the effects of delayed casting on the slump behavior and compressive strength of Grade 30 concrete, particularly when re-dosed with low-range superplasticizer. Understanding these effects is crucial because the slump behavior directly influences the ease of placement, compaction, and overall quality of the concrete, while compressive strength remains a key determinant of the structural integrity of the hardened concrete (Shetty, 2013).

The delayed casting scenario mimics real-world conditions where construction projects face unexpected interruptions, leading to prolonged times between mixing and pouring. This research also explores how re-dosing with superplasticizers can potentially mitigate the adverse effects of such delays. While the use of superplasticizers is well documented in enhancing the initial workability of concrete, their effectiveness in restoring slump behavior after a time delay and their impact on the final compressive strength are areas that require further investigation.

Therefore, this study seeks to address the knowledge gap by systematically exploring the slump behavior and compressive strength of Grade 30 concrete under delayed casting conditions, followed by re-dosing with low-range superplasticizer. The results of this research are expected to contribute to improved guidelines for concrete construction practices, especially in scenarios where delays between mixing and casting are unavoidable. Additionally, it will provide valuable insights into the appropriate use of superplasticizers to maintain the desired workability and ensure optimal compressive strength, thus enhancing the quality and longevity of concrete structures (Mehta & Monteiro, 2014).

1.2 Importance of the Study

In the dynamic and often unpredictable environment of construction projects, delays between the mixing and casting of concrete are commonplace. These delays can stem from various factors, including supply chain disruptions, adverse weather conditions, equipment malfunctions, and logistical challenges (Okpala & Aliaa Roslan, 2019). Such interruptions can significantly impact the fresh concrete's properties, particularly its workability, which is typically measured by slump. A reduction in slump during delayed casting complicates the placement and compaction processes, potentially leading to poor concrete performance, including increased voids and segregation (Ravindrarajah, 2003).

Contractors frequently address slump loss by adding water to the concrete mix. While this approach can temporarily restore workability, it adversely affects the water-to-cement ratio, resulting in diminished compressive strength and reduced durability of the hardened concrete (Aïtcin, 2015). Elevated water content not only lowers the concrete's strength but also increases its porosity, making it more susceptible to environmental degradation and shortening its service life (Hover, 2011). For Grade 30 concrete, which is extensively used in critical infrastructure such as bridges, highways, and high-rise buildings, failing to achieve the specified compressive strength can compromise structural integrity and lead to costly repairs and safety hazards.

This study is pivotal as it explores an alternative solution to maintaining concrete workability without compromising its strength by re-dosing with low-range superplasticizers (LRSP). Superplasticizers are advanced admixtures that enhance the dispersion of cement particles, thereby improving the concrete's flowability and maintaining its slump even after delays (Chen et al., 2021). By investigating the impact of LRSP re-dosing, this research aims to provide a viable method for restoring slump without increasing the water content, thereby preserving the concrete's compressive strength and durability.

Understanding the interaction between delayed casting and LRSP re-dosing is essential for optimizing concrete mix designs and ensuring that Grade 30 concrete meets the stringent performance requirements necessary for modern construction projects. This knowledge is particularly crucial for large-scale infrastructure projects where consistency and reliability of concrete properties are paramount for safety and longevity. Moreover, the findings from this study will offer valuable insights for civil engineers, construction managers, and material scientists. By addressing the challenges associated with delayed casting, this research contributes to minimizing material waste, reducing project delays, and enhancing the overall quality of concrete structures. Additionally, it supports the development of best practices and guidelines for the effective use of superplasticizers, fostering innovation and improving construction efficiency.

In summary, this study addresses a critical issue in the construction industry by providing a sustainable and effective method to maintain the workability and strength of Grade 30 concrete during delayed casting scenarios. The outcomes are expected to enhance construction practices, ensure the durability of structures, and contribute to the advancement of concrete technology.

1.3 Problem Statement

Concrete's performance can be significantly affected by various factors during its preparation and curing phases. One critical aspect that influences concrete behavior is the timing of its casting and any subsequent adjustments made to the mixture. In construction projects, delays in casting can lead to changes in the properties of the concrete, which may impact both its fresh and hardened states. Understanding how these delays affect concrete, specifically Grade 30 concrete is crucial for ensuring its desired performance and structural integrity.

When concrete is delayed in its casting, it often requires re-dosing to restore its workability and consistency. This process involves adding either water or chemical additives such as superplasticizers. While water addition is a common approach to regain workability, it can dilute the mix and compromise the concrete's final properties. Alternatively, low-range superplasticizers are used to improve the workability without significantly altering the mix's water-cement ratio. However, the effectiveness of these methods in restoring the original properties of the concrete, such as slump and compressive strength, needs to be thoroughly investigated to determine the best practice for maintaining concrete quality.

Another challenge arises when attempting to determine the optimal dosage of low-range superplasticizers needed to counteract the effects of delayed casting. Too little superplasticizer may not sufficiently restore workability, while too much can affect the mix’s strength and durability. Hence, precise control over the amount of superplasticizer is necessary to achieve the desired slump and compressive strength. This investigation is essential for optimizing concrete performance and ensuring that it meets the required standards even after experiencing delays during construction.

1.4 Aim and Objectives

The aim of this research is to investigate the impact of varying dosages of low-range superplasticizer required for re-dosing to regain the original slump on Grade 30 concrete due to delay casting. The objectives of this study are:

i. To compare the fresh properties of untreated concrete, concrete treated with water addition, and concrete re-dosing with low-range superplasticizer.
ii. To compare the hardened properties of untreated concrete, concrete treated with water addition, and concrete re-dosing with low-range superplasticizer.
iii. To determine the optimal dosage of low-range superplasticizer required for re-dosing to regain the original slump of Grade 30 concrete due to delay casting.

1.5 Scope and Limitation of the Study

This study identifies several task scopes and will focus on examining the effects of delayed casting on the slump behavior and compressive strength of Grade 30 concrete after re-dosing with a low-range superplasticizer. The appropriate mix proportion will be determined based on trial mix results with the target being a 28-day compressive strength of 30 MPa, classified as moderate-strength concrete. It is important to note that these findings may not be applicable to mortar or high-strength concrete due to differing mixture proportions. Once the mix proportion is finalized, sample specimens will be cast accordingly and cured for 7 and 28 days, following ASTM and BS EN standards for raw material preparation and casting procedures.

In this study, a low-range polycarboxylic ether (PCE) based superplasticizer, MasterGlenium Ace 8333, will be used during the actual mixing process. The superplasticizer dosage will range from 0.1% to 0.7% by weight of cement, applied in increments of 0.1%. Additional water will be added during re-dosing. Re-dosing is limited to delayed casting scenarios where the slump drops to 50 mm.

Two types of tests will be conducted in this study: fresh properties tests and hardened tests. The fresh properties tests will focus on the workability of the concrete, and data will be collected on fresh density, slump value, Vebe time, compacting factor, and sieve analysis results. The hardened tests will primarily involve compressive strength testing of 150 mm × 150 mm × 150 mm cubic specimens using the universal compression machine.

1.6 Contribution of the Study

This study offers practical insights into maintaining concrete workability without compromising its compressive strength, particularly in scenarios involving delayed casting. By examining the effects of re-dosing with low-range superplasticizers, the research addresses a critical gap in the existing literature, where the practice of re-dosing to counteract slump loss has not been extensively explored.

The findings of this research have the potential to significantly enhance construction practices. By providing a better understanding of how re-dosing can restore slump and ensure the desired compressive strength, the study can lead to improved project efficiency, reduced material waste, and minimized risks of structural deficiencies that may arise from improper slump restoration methods. These benefits can help reduce costs and prevent delays in construction projects, contributing to more sustainable and efficient resource management in the industry.

Furthermore, this research adds a new dimension to the field of concrete technology, filling a knowledge gap in the application of superplasticizers during delayed casting. The results can serve as a foundation for future studies and offer practical guidelines for professionals in the construction industry, making it a valuable contribution to both academic research and real-world construction practices.

1.7 Outline of the Report

This report contains five chapters, which are the introduction, literature review, methodology, results and discussion and lastly, conclusion and recommendations.

Chapter 1 provides a general introduction, outlining the significance of the study, problem statement, aim and objectives, limitations and scope, and contributions of the research.

Chapter 2 reviews the literature, focusing on previous research on the application of superplasticizer and their effects on slump behaviour and compressive strength.

Chapter 3 details the methodology, summarizing the study's approach and discussing the tests to be conducted, such as fresh and hardened properties tests.

Chapter 4 presents the results and discussion, analyzing the data related to the workability and compressive strength of the concrete. This chapter provides a detailed analysis of how superplsticizer re-dosing and water addition affect the properties in the concrete.

Chapter 5 presents the conclusion and recommendations of the research. It concludes that the study's aim and objectives have been achieved, and offers recommendations for further enhancing the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review aims to examine the effects of delayed casting on Grade 30 concrete, with a particular focus on its slump behavior and compressive strength. It also examines the impact of SP and water addition on these properties.

The strategy of re-dosing superplasticizers has recently attracted significant attention due to its potential to improve concrete properties by enhancing workability and strength. Superplasticizers help reduce the water-cement ratio while maintaining workability, which is crucial for optimizing concrete performance. However, the effectiveness of re-dosing in the context of delayed casting needs thorough investigation to understand its impact on concrete’s physical properties and its optimum dosage. Alternatively, water addition plays a fundamental role in influencing concrete’s consistency and strength. The effects of adding water after a delay in casting can significantly alter the concrete's characteristics, which requires detailed examination to determine how it impacts the final properties of the mix.

This chapter reviews the relevant research on these topics, focusing on superplasticizer re-dosing or water addition affects concrete properties. It aims to identify existing knowledge gaps and provide a foundation for the experimental investigation, which will address one of these aspects in detail.

2.2 Superplasticizer

Superplasticizers, also known as high-range water reducers, are crucial admixtures in modern concrete technology. According to Papayianni et al. (2004), these chemical additives significantly enhance the workability and fluidity of concrete without increasing the water content. Their ability to improve the performance of concrete mixtures has made them indispensable in producing high-strength, durable, and workable concrete. According to ASTM standards, chemical admixtures, including superplasticizers, are classified into several types based on their functions and effects on concrete as shown in Table

2.2. Specifically, superplasticizers fall under Type F (High-Range Water-Reducing Admixtures) as per ASTM C494/C494M (2017).

Table 2.1: Types of Chemical Admixtures.

Type	Description
A	Water-reducing admixtures
B	Retarding admixtures
C	Accelerating admixtures
D	Water-reducing and retarding admixtures
E	Water-reducing and accelerating admixtures
F	Water-reducing, high range admixtures
G	Water-reducing, high range, and retarding admixtures
S	Specific performance admixtures

2.2.1 Roles of Superplasticizer

Superplasticizers (SPs), also known as high-range water reducers, play a pivotal role in modern concrete technology. They are primarily used to enhance the workability of concrete mixtures, which facilitates the mixing, transportation, and placement of concrete. By significantly improving workability, SPs allow for a reduction in the water content required for a given slump, thereby increasing the fluidity of the mix. This is particularly beneficial for producing high-strength and high-performance concrete, where a lower water-to-cement ratio is essential for achieving the desired strength and durability without compromising workability (Bentz and Aïtcin, 2008; Mardani-Aghabaglou et al., 2013). Superplasticizers enable a notable reduction in the amount of water needed while maintaining the same workability, which leads to an increase in the compressive strength of the concrete (Alsadey, 2015). Additionally, the enhanced flowability of the concrete facilitated by SPs allows for easier placement in complex forms and reduces the need for excessive vibration (Kapelko, 2006; Lou et al., 2013).

Beyond improving workability, superplasticizers influence the rheological properties of concrete, including its viscosity and cohesion. They modify the interaction between cement particles, thereby improving the consistency and stability of the concrete mix (Chandra and Björnström, 2002). The use of SPs helps reduce segregation and bleeding—common issues in concrete with high water content—resulting in a more homogeneous mixture and enhanced overall quality (Dhakal and Wanichlamlert, 2014). Furthermore, SPs contribute to the stability of the mix by preventing the separation of aggregates from the cement paste, ensuring a uniform distribution of materials.

2.2.2 Mechanism of Action

The mechanism of action of superplasticizers in concrete is pivotal for optimizing workability and performance. They work primarily through electrostatic repulsion and steric hindrance mechanisms. Electrostatic repulsion occurs when superplasticizers adsorb onto cement particles, imparting a negative charge that repels other particles, thus reducing the need for water while maintaining or improving workability (Aicha, 2020; Hsu et al., 2000).

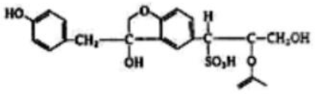
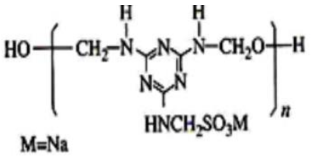
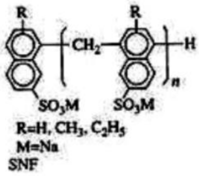
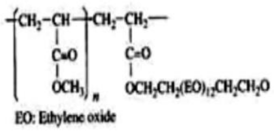
On the other hand, steric hindrance involves the superplasticizer molecules physically separating cement particles due to their large molecular size, further reducing the water requirement (Laskar & Bhattacharjee, 2013; Benaicha et al., 2019). This reduction in water content while retaining high workability is crucial for achieving desired concrete consistency and strength. Additionally, some superplasticizers, such as polycarboxylate ethers, exhibit both mechanisms, enhancing their effectiveness (Arel & Aydin, 2017; Lin et al., 2019).

The combined action of these mechanisms contributes to improved slump retention and a reduction in the viscosity of the concrete mix, making it easier to work with and pump (Erdoğdu, 2004; Malhotra, 1981). The ability to reduce water content without sacrificing workability also leads to increased compressive strength and durability of the hardened concrete (Chandra & Björnström, 2002; Dhakal & Wanichlamlert, 2014).

2.2.3 Types of Superplasticizer

The journey of superplasticizers began in the early 20th century as researchers sought to improve the properties of concrete. The initial focus was on achieving better workability and reducing the water-cement ratio. Early additives were primarily based on natural substances. However, as the demands for high-performance concrete grew, particularly with the advent of large-scale construction projects and high-strength concrete applications, the need for more effective and specialized additives became evident. This led to the development of synthetic superplasticizers, each generation building on the knowledge gained from the previous one. The types of superplasticizers are classified in Table 2.2.

Table 2.2: Superplasticizers Classification (Shah et al., 2014; Łaźniewska-Piekarczyk et al., 2015).

Class	Origin	Generation
Lignosulphonates (LS) 	Derived from neutralization, precipitation, and fermentation processes of the waste liquor obtained during production of paper-making pulp from wood	I
Sulphonated melamine formaldehyde (SMF) 	Manufactured by normal resinification of melamine – formaldehyde	II
Sulphonated naphthalene formaldehyde (SNF) 	Produced from naphthalene by oleum or SO3 sulphonation; subsequent reaction with formaldehyde leads to polymerization and the sulphonic acid is neutralized with sodium hydroxide or lime	II
Polycarboxylic ether (PCE) 	Free radical mechanism using peroxide initiators is used for polymerization process in these systems	III

In construction industry, Lignosulfonates (LS) are often used as first-generation superplasticizers. LS derived from lignin which is a natural polymer present in wood, were the first superplasticizers developed in the early 20th century. These compounds were among the first to demonstrate the ability to enhance concrete workability by dispersing cement particles. Chandra and Björnström (2002) found that lignosulfonates significantly improved the workability of Portland cement mortars, though they exhibited limited effectiveness in retaining slump over time compared to later generations of SPs. Furthermore, Arel and Aydin (2017) noted that while LS is effective in reducing the viscosity of cement slurries, it has limitations in terms of high dosage requirements and reduced performance in high-strength concrete.

In the 1960s, the concrete industry saw the introduction of sulfonated melamine formaldehyde (SMF) and sulfonated naphthalene formaldehyde (SNF) as the second generation of superplasticizers (Edmeades & Hewlett, 2003). These synthetic compounds offered significant improvements over lignosulfonates, including better dispersion of cement particles and longer slump retention. Kasami et al. (1979) reported that SMF-based SPs provided superior workability and longer slump retention compared to LS, making them suitable for high-strength concrete applications. Harkouss and Hamad (2016) conducted a comparative study and found that SNF-based superplasticizers were highly effective in reducing the water-cement ratio while improving the concrete's strength and durability.

The late 1980s brought about the third generation of superplasticizers: polycarboxylate ethers (PCE) (Lei & Plank, 2011). These advanced additives marked a significant technological leap, offering exceptional performance in terms of dispersion, slump retention, and concrete strength. Benaicha et al. (2019) highlighted that PCEs provided a higher degree of dispersion and superior slump retention compared to SMF and SNF. Their effectiveness in self-compacting concrete was particularly noted. Lin et al. (2019) demonstrated that PCE-based superplasticizers offer enhanced rheological properties and are highly effective in reducing the water-cement ratio without adversely affecting the setting time of concrete.

The evolution of superplasticizers from lignosulfonates to polycarboxylate ethers reflects significant advancements in concrete technology.

Each generation has contributed to improving the performance and versatility of concrete, catering to increasingly complex construction needs and high-performance requirements.

2.2.4 Advantages of Superplasticizer

They offer several significant advantages, making them an essential component in modern concrete technology. First, SPs significantly increase the workability of concrete without the need for additional water. This enhancement in workability allows for easier placement, compaction, and finishing of concrete. The increased fluidity helps in achieving complex and intricate designs, particularly in high-strength and self-compacting concretes (Aicha, 2020; Mardani-Aghabaglou et al., 2013). For instance, research by Hsu et al. (2000) demonstrated that superplasticizers improve the flowability of concrete mixtures, making them suitable for high-performance applications.

By reducing the water-to-cement ratio while maintaining workability, superplasticizers contribute to the development of higher compressive strength and durability of concrete. This effect is crucial for structures exposed to severe environmental conditions. According to Alsadey (2012) and Malhotra (1981), the use of superplasticizers leads to significant improvements in both the strength and durability of concrete by optimizing the cement hydration process and minimizing porosity.

Furthermore, SPs help in reducing segregation and bleeding in concrete mixtures. This is particularly beneficial in preventing the formation of voids and ensuring uniformity in concrete properties. As noted by Kapelko (2006), the controlled dispersion of cement particles facilitated by superplasticizers minimizes the risk of segregation and bleeding, thereby enhancing the overall quality of the concrete.

Moreover, the use of SPs offers greater flexibility in mix design. This flexibility allows for the incorporation of various supplementary cementitious materials, such as fly ash or slag, which can improve the sustainability and performance of concrete (Kamran & Mishra, 2014). By optimizing the mix design, superplasticizers enable the use of lower-grade cements or recycled materials without compromising the quality of the final product (Papayianni et al., 2004).

While superplasticizers represent an additional cost in concrete production, their benefits often outweigh this expense. The ability to achieve higher strength with lower cement content and reduced need for additional water leads to cost savings in both materials and construction processes. Furthermore, the enhanced durability can reduce maintenance costs over the lifespan of the concrete structure (Dhakal & Wanichlamlert, 2014).

2.2.5 Optimum Dosage of Superplasticizer

The efficiency of superplasticizing admixtures is affected by several variables, including dosage, admixture type, cementitious materials used, and mixture proportions (Onyeka et al., 2023). Based on particular application requirements, substantial research has been done to identify the optimum dosage to optimize the performance of these admixtures. Malhotra (1981) indicate that introducing a second dosage of superplasticizer can lead to substantial increases in the slump of superplasticized concretes for several hours. However, the addition of a third dosage is generally not found to be beneficial, except in one particular case. Murugesan et al. (2023) found that PC-based admixture showed a good impact with moderate workability retention and water reduction of 20–35%, with the saturation dosage of 1.5% of PC-based admixture. On the other hand, another research shown that 0.3% is the optimum dosage which give the highest strength (Aicha, 2020).

Although adding more superplasticizer can increase compressive strength, there is an optimal amount. According to Bayerhrcak (2023), the findings proved that adding more SP may result in better slump but it will decrease the ultimate strength of the concrete. Alsadey (2012) emphasized that increasing the dosage beyond this limit results in a reduction of compressive strength due to bleeding and segregation, compromising the cohesiveness and uniformity of the concrete. Hence, several researches indicate that compressive strength will decrease if the applied dosage exceeds the optimum level (Salem et al., 2016) (Omran & Alsadey, 2022).

2.3 Concrete Properties

Concrete properties are critical in determining the performance and quality of the material in various construction applications. These properties include workability, density, and compressive strength, all of which are significantly influenced by mix design, environmental conditions, and additives like superplasticizers.

2.3.1 Workability

Workability refers to the ease with which fresh concrete can be mixed, placed, compacted, and finished without segregation. High workability ensures that the concrete can fill the formwork completely and encase the reinforcement bars without leaving voids. The presence of superplasticizers in concrete improves workability by reducing the water-to-cement ratio, enhancing the fluidity of the mix without compromising strength (Neville, 2011). Studies indicate that superplasticizers can modify the yield stress and plastic viscosity of concrete, resulting in improved slump behavior (Mangat et al., 2015).

Various tests are used to measure the workability of concrete, and these tests are suitable for different levels of workability. According to BS 1881, four methods for determining concrete workability are the Slump Test, Compacting Factor Test, Vebe Test, and Flow Test. Each method is appropriate for different degrees of workability, as summarized in Table 2.3.

Table 2.3: Workability Methods.

Workability	Method
Very Low	Vebe time
Low	Vebe time, compacting factor
Medium	Compacting factor, slump
High	Compacting factor, slump, flow table
Very High	Flow table

The Slump Test is commonly used for medium to high workability and provides a quick measure of concrete consistency. Figure 2.1 shows the slump test according to different standards: BS, BS EN, and ASTM. The slump test classifies the types of slump based on the resulting slump value, which indicates the workability of the concrete. A True Slump occurs when the concrete retains its shape and the slump is measured directly. This type of slump is desirable as it indicates a workable mix with adequate consistency. In contrast, a Shear

Slump happens when one side of the concrete slumps more than the other, suggesting that the mix may be too wet or poorly mixed. Finally, a Collapse Slump is observed when the concrete collapses completely, indicating excessive workability. This type of slump signifies that the mix is too fluid and may not be suitable for most structural applications, as it can lead to segregation and insufficient strength.

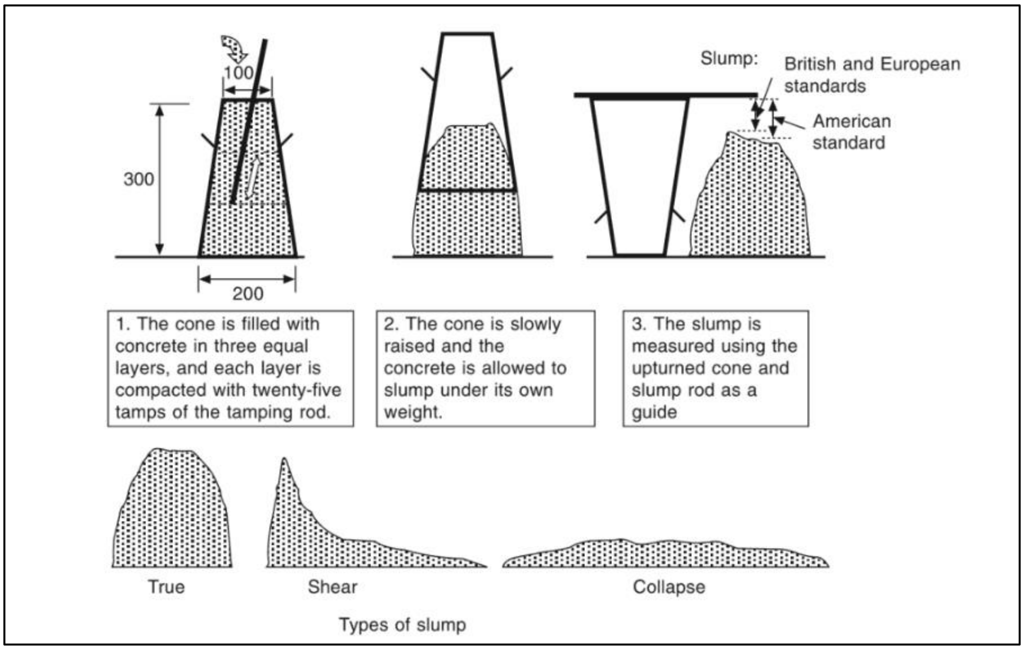


Figure 2.1: Slump Test (Newman & Choo, 2014).

The Compacting Factor Test is suitable for medium to high workability, especially in mixes that are not highly fluid. The Vebe Test is appropriate for very low to low workability, measuring the time required to achieve a given degree of workability. The Flow Test is used for very high workability, typically for self-compacting concrete (Gharpedia, 2024). According to Gharpedia (2024), the following comparative table summarizes the degrees of workability and application as shown in Table 2.4.

Table 2.4: Comparative Table of Workability Tests Result and Application (Gharpedia, 2024; Neville, 2011).

Degree of Workability	Slump Test	Compacting Factor	Vebe Test	Application
Very Low	0 – 25mm	0.78	20-10s	Vibrated concrete for pavement roads
Low	25 – 50mm	0.85	10 - 5s	Mass concrete foundations without vibration
Medium	50 – 100 mm	0.92	5 - 3s	Reinforced concrete
High	100 – 180 mm	0.95	3 - 1s	Highly reinforced concrete

2.3.2 Density

Density is a fundamental property of concrete, representing its mass per unit volume. It is directly linked to the mix's composition, particularly the aggregates and the water content. The density of concrete typically ranges between 2200 and 2400 kg/m³ for normal-weight concrete (Domone, 2018). Superplasticizers can indirectly influence density by improving the dispersion of cement particles, which allows for a more uniform mix. This uniformity enhances the hydration process, potentially increasing the compactness and, consequently, the density of the hardened concrete (Al-Amoudi et al., 2007).

2.3.3 Compressive Strength

Compressive strength is the capacity of concrete to withstand axial loads without failure, measured in megapascals (MPa). This property is a crucial indicator of the concrete's durability and structural integrity. The addition of superplasticizers helps in achieving higher compressive strength by reducing the water-to-cement ratio while maintaining workability (Mehta & Monteiro, 2014). Superplasticizers enable the formation of a denser cement paste matrix, leading to improved hydration and strength development. Table 2.5 shows the classification of concrete based on the compressive strength value.

Table 2.5: Classification Of Concrete Based On The Compressive Strength Value (Grdić et al., 2023).

Concrete Type	Compressive Stregnth (MPa)
Normal Strength Concrete	20-50
High Strength Concrete	50-100
Ultra-High Performance Concrete	100-150
Reactive Powder Concrete	>150

According to BS EN 12390-3:2002, Figure 2.1 indicates the satisfactory failures of cube specimens. All four visible sides exhibit nearly equal cracking, typically with minimal damage observed on the surfaces in contact with the platens. In addition, Figure 2.2 shown nine patterns of unsatisfactory failures of cube specimens.

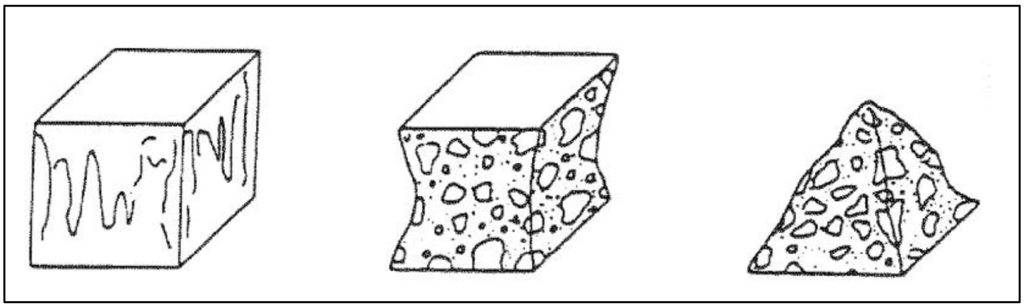


Figure 2.2: Satisfactory Failures of Cube Specimens (BS EN, 2002).

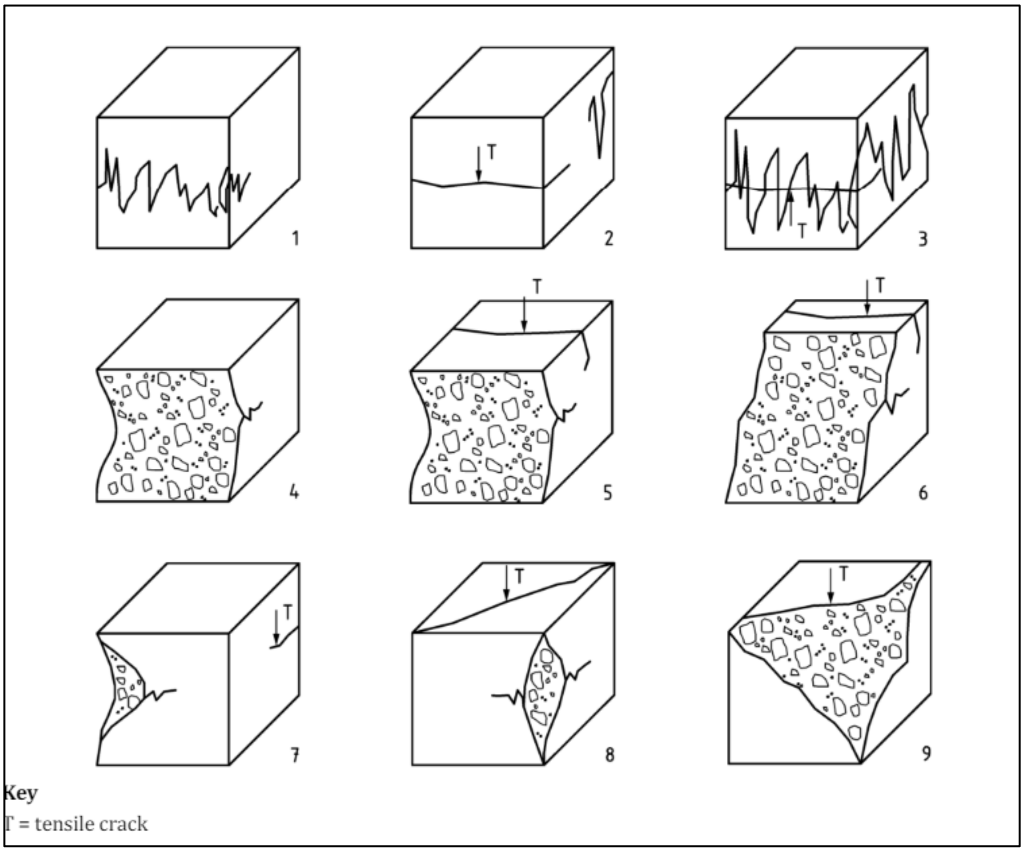


Figure 2.3: Unsatisfactory Failures of Cube Specimens (BS EN, 2002).

2.4 Factors Affecting Concrete Properties

Concrete properties, including workability, density, and compressive strength, are influenced by various factors that interact in complex ways. Understanding these factors is crucial for optimizing concrete performance, particularly when using superplasticizers and dealing with delayed casting. The main factors affecting concrete properties include the composition of the mix, the properties of the materials used, and the conditions under which the concrete is mixed and cured.

2.4.1 Composition of the Mix

The composition of the concrete mix, including the proportions of cement, water, aggregate, and admixtures, plays a significant role in determining its properties. The water-to-cement ratio is a critical factor; a higher ratio generally increases workability but can reduce compressive strength. Conversely, a lower water-to-cement ratio improves strength but may decrease workability (Neville, 2011). The inclusion of superplasticizers allows for a lower water-to-cement ratio while maintaining or even improving workability, which can be particularly beneficial when dealing with delayed casting.

2.4.2 Properties of the Materials

he properties of the individual materials used in the mix, such as the type and gradation of aggregates, the type of cement, and the quality of the water, also affect concrete properties. Aggregates with different sizes and shapes can influence the workability and density of the concrete. For example, well-graded aggregates improve the packing density, leading to a more stable and durable concrete mix (Ali, 2023). The type of cement used can affect the setting time and strength development, while the quality of the water must be controlled to avoid introducing impurities that could impair the concrete’s performance (Mangat, Khatib & Clay, 2015).

2.4.3 Mixing and Curing Conditions

The conditions under which concrete is mixed and cured significantly impact its properties. Proper mixing ensures a uniform distribution of materials, which is essential for achieving consistent workability and strength. Over-mixing or under-mixing can lead to segregation or inadequate bonding between the ingredients. Curing conditions, including temperature and humidity, affect the hydration process and strength development. Inadequate curing can lead to insufficient hydration and, consequently, reduced compressive strength and durability (Gharpedia, 2024).

2.4.4 Superplasticizers

Superplasticizers significantly improve the workability of concrete by reducing its water content while maintaining the desired slump. According to Aicha (2020), superplasticizers enhance the rheological properties of self-compacting concrete, allowing for better flowability and reduced viscosity. This improvement is crucial for applications requiring high fluidity and ease of placement, particularly in complex forms and congested reinforcement situations (Aicha, 2020).

Similarly, studies by Kasami et al. (1979) demonstrate that superplasticizers effectively increase the slump of concrete mixtures, which correlates with enhanced workability. This increased slump is directly related to the superplasticizer's ability to reduce internal friction and improve the dispersion of cement particles (Kasami et al., 1979). According to the slump test results presented by Alsadey and Mohamed (2020), the slump demonstrated a consistent increase with higher superplasticizer dosages. This trend is illustrated in Figure 2.3, indicating a corresponding improvement in flowability and workability of the concrete.

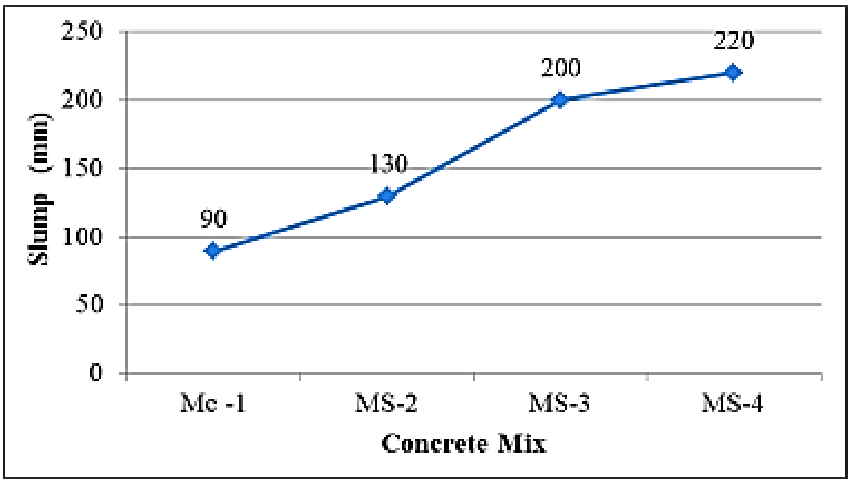


Figure 2.4: Slump against Cocrete Mix with Increasing Dosage (Alsadey & Mohamed, 2020).

The retention of slump, or the maintenance of workability over time, is a critical factor for the usability of concrete, especially in ready-mix applications. Erdoğdu (2004) investigated the effect of retempering with superplasticizers on slump loss, revealing that while initial slump improvements are substantial, the retention of this workability over extended periods can vary. The study showed that superplasticizers help in maintaining slump for a longer duration compared to non-modified concrete, although the extent varies with the type of superplasticizer used. Dhakal and Wanichlamlert (2014) further explored slump retention by time-splitting the superplasticizer dose. Their findings indicated that controlled dosing can effectively prolong the workability of concrete, mitigating the common issue of slump loss during transportation and placement (Dhakal & Wanichlamlert, 2014).

Superplasticizers also influence the compressive strength of concrete. Research by Malagavelli and Paturu (2012) highlights that while superplasticizers improve workability, their impact on strength is also significant. Concrete mixtures with optimal superplasticizer dosages exhibited enhanced compressive strength due to better cement dispersion and reduced water-to-cement ratios (Malagavelli & Paturu, 2012). Salem et al. (2016) observed that the use of superplasticizers increases compressive strength by improving compaction efficiency, resulting in denser concrete. This densification effect leads to higher compressive strength values in hardened concrete mixes. Similarly, Pereira et al. (2012) emphasized that superplasticizers enhance compaction efficiency, resulting in denser concrete and thereby improving compressive strength. Due to its ultra-long side chain, superplasticizers have a substantial steric hindrance effect. This can accelerate cement hydration and generate dense C-S-H gel by increasing the area of contact between cement particles and water. This C-S-H gel fills the pores in cement paste, resulting in compactness and improved mechanical and durability performance.

On the other hand, excessive use of superplasticizers can lead to diminished strength gains. Mardani-Aghabaglou et al. (2013) found that the dosage of superplasticizers must be carefully controlled to avoid adverse effects on the concrete's mechanical properties. Their study emphasized the need for a balance between workability and strength, highlighting that an optimal dosage is crucial for achieving the best results (Mardani-Aghabaglou et al., 2013). There are several researcher agree that the compressive strength of the concrete increase as the dosage of superplasticizer increases, but the compressive strength of concrete decrease when it reached the optimum dosage. Alsadey & Mohamed (2020) demonstrate that the ultimate compressive strength was achieved when optimum dosage of 0.8% superplasticizer was added in, and hence the compressice strength decreased when 1.0% of superplasticizer added in as shown in Table 2.6.

Table 2.6: The Compressive Strength of Superplasticizer Concrete Mixes (Alsadey & Mohamed, 2020).

Concrete Mix	Dosage of Sikament®-520, %	Compressive Strength (N/mm^2)
Mc-1	0	30
Mc-2	0.8	39
Mc-3	1.0	33
Mc-4	1.2	29

2.5 Impact of Delayed Casting on Concrete Properties

Concrete's performance can be significantly affected by delayed casting due to factors such as loss of workability and reduced compressive strength. Delayed casting occurs when fresh concrete is not placed immediately after mixing due to logistical challenges, traffic, equipment malfunctions, or adverse weather conditions (Mahzuz et al., 2020). As a result, fresh concrete undergoes hydration, leading to stiffening, loss of workability, and potential cold joints between layers. This section reviews how delayed casting impacts key concrete properties such as workability, compressive strength, and durability, based on findings from several studies.

2.5.1 Workability Loss

The workability of fresh concrete deteriorates over time after mixing due to hydration and evaporation, which significantly influences concrete placement. According to Kumar and Biable (2020), the slump value and compaction factor of concrete decrease as the time delay increases, leading to reduced workability. They noted that with a 2-hour delay, the slump value can fall to zero, making the concrete unworkable. Mahzuz et al. (2020) also observed that without water re-dosing, the workability of the concrete is lost after approximately 180 minutes, rendering the concrete dry and difficult to place in molds. This loss of workability can result in improper compaction, leading to voids and poor consolidation in the final structure.

2.5.2 Compressive Strength Reduction

Compressive strength is a critical property for structural integrity, and it can be significantly reduced due to delayed casting. The hydration process begins soon after mixing, and if the concrete is left too long before casting, it may begin to set before placement. Studies show that delayed casting without any adjustments can result in a substantial reduction in compressive strength. For instance, Kumar and Biable (2020) reported a 28.28% reduction in the 28-day compressive strength of concrete cast after a 2-hour delay compared to concrete cast with only a 30-minute delay. Mahzuz et al. (2020) found that after a 180-minute delay, the compressive strength of concrete began to drop sharply if no water was added to restore workability.

However, in cases where superplasticizers or water are re-dosed to restore workability, the reduction in compressive strength can be minimized. Yousri and Seleem (2004) observed that retempering concrete with high-range water reducers (HRWR) can mitigate strength losses associated with delayed casting. HRWR can maintain slump and delay the setting time, allowing for longer workability without significant strength loss. Their results showed that compressive strength could be maintained or even slightly increased with appropriate retempering methods.

2.5.3 Durability Concerns

The durability of concrete is also impacted by delayed casting. Poor workability due to prolonged delays can lead to improper compaction, resulting in increased porosity and permeability, which in turn reduces durability. Additionally, adding extra water to restore workability increases the water-to-cement (w/c) ratio, which negatively affects the long-term strength and durability of the concrete. According to Mahzuz et al. (2020), adding water during delayed casting leads to a drop in strength after the final setting time and may cause increased susceptibility to cracking and environmental degradation.

2.6 Summary

This study focuses on normal strength concrete to examine the effects of varying dosages of superplasticizers (SP) and additional water under delayed casting conditions, a topic that has not been extensively explored in current research.

Delayed casting is known to negatively impact concrete properties, such as workability and compressive strength, due to ongoing hydration and moisture loss. This research goes further by investigating how these properties can potentially be restored through the re-dosing of polycarboxylate ether (PCE)-based superplasticizers and the addition of water.

While PCE superplasticizers are well-established for enhancing workability and reducing water requirements without compromising strength, the effects of re-dosing them after casting delays, combined with added water, have not been thoroughly explored. This study aims to fill that gap by investigating how varying dosages of PCE superplasticizers, along with water, influence concrete consistency, workability, and compressive strength under delayed casting conditions. This investigation is important because it proposes a practical solution to mitigate the adverse effects of casting delays, providing valuable insights for construction practices where such delays are common. Additionally, Table 2.7 summarizes the findings of previous studies in this area. A clear gap emerges: no research has comprehensively investigated both the effects of water addition and the re-dosing of superplasticizer (SP) following delayed casting, using all available workability tests.

Table 2.7: A Summary of the Different Types of Concrete and Superplsticizers.

Authors	Type of Concrete Used	Types of Superplasticizers	Properties That Had Been Determined
Olowofoyeku et al., 2019	Self-Compacting Concrete (SCC)	Conplast SP 561, SP 430, SP 264	Workability (slump flow, v-funnel, l-box), Compressive Strength, Segregation Resistance
Antoni et al., 2017	Concrete with Different Cement Types	Polycarboxylate-based Superplasticizers	Slump retention, setting time, workability, compressive strength, effect of cement type
Alsadey, 2012	Normal Strength Concrete (30 N/mm²)	Sikament® R2002	Slump loss, Compressive Strength, Workability, Optimum dosage determination
Baroninsh et al., 2011	High-Performance Concrete (HPC)	Polycarboxylates (Semflow MC)	Slump, flow, Compressive Strength, Porosity, Depth of Water Penetration

Table 2.7 (Continued)

Mahzuz et al., 2020	Standard concrete	None (Water added for workability)	Workability, Compressive Strength at various delay intervals, effects of water addition on compressive strength
Kumar and Biable, 2020	M25 Grade Concrete	Not specified	Compressive strength reduction due to delayed casting
Yousri and Seleem, 2004	Standard concrete (w/c ratios: 0.5, 0.588, 0.65)	High-Range Water Reducers (HRWR)	Workability, Compressive Strength, and impact of retempering on compressive strength

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter covers the methodology to study the slump behavior and compressive strength of the Grade 30 concrete after addition of water or re-dosing of superplaticizer under delayed casting. Every step of the process is covered in depth, from raw material preparation and mixing techniques to testing procedures. There will be two phases in the experiment: the trial mix and the actual mix. Identifying the optimum water-to-cement (w/c) ratio, the slump value will be achieve, and a sufficient concrete cube strength of at least 30MPa after 28 days are the primary objectives of the trial mix experiments. Without any admixture or water addition during the actual mix stage, the resulting mix is utilized as a control mix. In contrast, the objective of this phase is to collect test data on the compressive strength and slump behavior of the actual mix after superplasticizer. Tests for both fresh properties and hardened properties were carried out. Figure 3.1 demonstrates the overall project workflow chart.

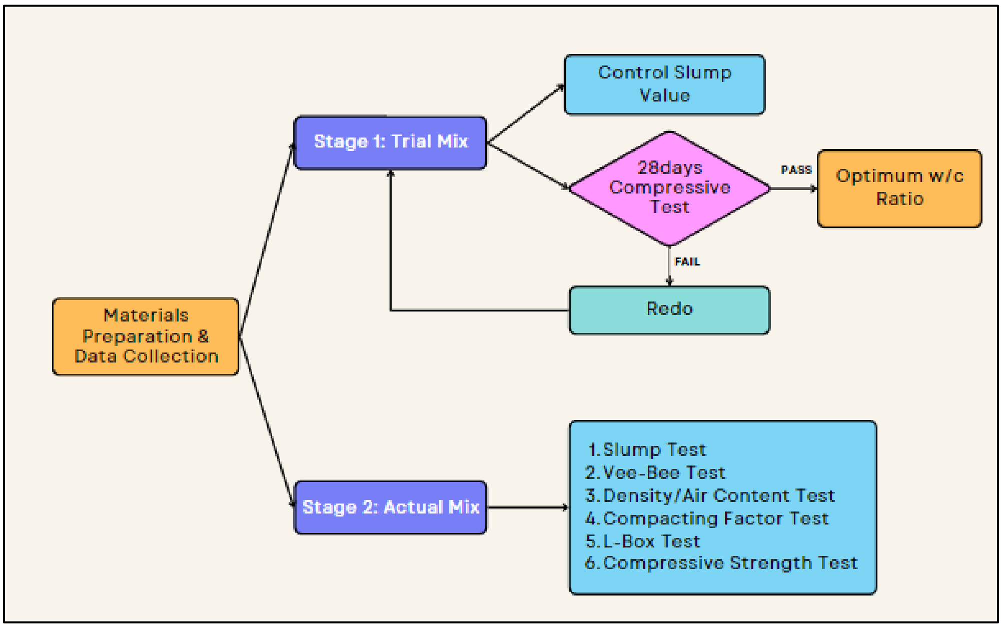


Figure 3.1: Overall Project Workflow Chart.

3.1 Raw Materials

This section covers the procedures and methods used to prepare the raw materials needed for the experimental testing. The raw materials comprise superplasticizer, water, coarse and fine aggregates, and Ordinary Portland Cement (OPC).

3.1.1 Ordinary Portland Cement (OPC)

In this study, the type of cement used is Type I Ordinary Portland Cement (OPC), which is manufactured and supplied by YTL Cement Bhd. As illustrated in Figure 3.2, the brand name of cement product is known as Orang Kuat, and it is a high strength Portland cement that meets CEM I 52.5N standards.

Figure 3.2: Orang Kuat Cement.

Orang Kuat cement has been certified in accordance with MS EN 197-1:2014, a Malaysian standard. The purchased cement packets were opened and kept in an airtight container to facilitate the mixing of concrete. This procedure ensured that the cement is kept in an environment that is monitored and free of pollutants.

3.1.2 Fine Aggregate

Sand often known as fine aggregate, is an essential component in the making of concrete. This study was utilized fine aggregates that are supplied by local suppliers that have been manufactured in accordance with the ASTM C33 Standard. After calculating the amount of sand needed, the sand was put in a bucket for preparation, as demonstrated in Figure 3.3. The sand was cleansed with tap water to getting hydrated. After that, the aggregates was air dried in the sun for a few days to eliminate the surface moisture. With the implementation of these procedures, it ensured that the fine aggregate are in a state known as Saturated Surface Dry (SSD) for a suitable state for mixing concrete.

Figure 3.3: Fine Aggregate, or Sand.

In accordance with ASTM C33 (2023), fine aggregates were graded within a range of less than 9.5mm. Since at least 95% of aggregates must pass the 4.75mm sieve, the range of fine aggregate size used in this study was range 0.075mm to 4.75mm to make initial preparation easier. Gathered sand were sieved through a 4.75mm sieve to remove the aggregates that fall within this range.

3.1.3 Coarse Aggregate

Coarse aggregate is another important component in the concrete-making process. Similar to fine aggregates, coarse aggregates will also be supplied locally and manufactured in accordance with ASTM C33 Standard. The aggregates were put in a bucket for handling once the amount needed has been calculated as illustrated in Figure 3.4.

Figure 3.4: 10-20mm Coarse Aggregate.

After achieving saturated condition by a tap water wash, the aggregates were let to air dry for several days in the sun to obtain SSD condition by drying out the aggregates' surface. Two sizes of coarse aggregates, which are 10-20 mm and 5-10 mm, were utilized for the proposed composition of the concrete mix. To obtain aggregates within this range, the aggregates were put into an aggregate crusher to crush into smaller sizes as shown in Figure 3.5.

Figure 3.5: Aggregate Crusher.

Subsequently, the crushed aggregates will be passed through 20, 10, and 5 mm sieves, respectively. In this phase, the aggregates will be separated into two size ranges: 5–10 m and 10–20 mm. The aggregates will be collected in a bucket after separation.

3.1.4 Water

In this study, water was required for the mixing and curing of the concrete. In other words, this study will use lab tap water sourced from the municipal water system. Following the ASTM C1602 standard, it is ensured that the water utilized will not impact the strength and setting time of concrete. This was accomplished by ensuring that the water's overall density and solids content are not affected by any sediments or pollutants. Furthermore, the water were maintained at room temperature, or 27 °C. A clean bucket was readied to collect the water after the amount required has been calculated. After all the other components were prepared, concrete was made using water from the lab tap. This precaution helps to avoid contaminating the water with dust or other pollutants during the preparation of other materials by delaying the preparation of the water.

3.1.5 Superplasticizer

Master Builders Solutions Malaysia Sdn Bhd supplied superplasticizer, the main component in this study. In this study, a PCE type superplasticizer called MasterGlenium ACE 8333 was utilized as presented in Figure 3.6.

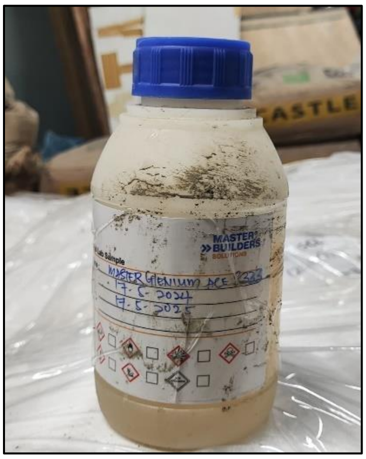


Figure 3.6: MasterGlenium ACE 8333.

The superplasticizers were kept in the proper containers at room temperature. Superplasticizer was taken out and placed into a container when it was needed for the re-dosing process, and its weight was recorded. Each mix's required amount of superplasticizer was precalculated.

3.2 Trial Mix

Before casting the actual concrete specimens for the study, it was essential to prepare and test trial mixes. The aim was to achieve a minimum cube crushing strength of 30 MPa and a slump within the range of 100±25 mm. Multiple trial mixes were designed and tested to determine the optimal water-to-cement (w/c) ratio, which was intended to be between 0.50 and 0.70.

After mixing, a slump test was conducted to measure the slump value. Subsequently, compression tests were performed at 7 days and 28 days to evaluate the compressive strength of each concrete specimen with varying w/c ratios. The trial mix that met the criteria of at least 30 MPa of characteristic strength at 28 days and a slump within the range of 100±25 mm was selected.

3.3 Mix Procedure

The mix procedure was carried out with compliance with ASTM C192/C192M-19. In this study, the mixing process was conducted using a concrete mixer as shown in Figure 3.7.

Figure 3.7: Concrete Mixer.

Furthermore, it will be necessary to prepare a mixing bowl and then uniformly distribute the dry mix inside of it. Cement, fine aggregate, and coarse aggregate are the parts of the dry mix. A weighing machine was used to measure the required amounts of OPC, fine and coarse aggregate, SP, and water, resulting in mixes with precise weight proportions. As an illustration, the fine aggregates were weighed using the weighing machine as seen in Figure 3.8.

Figure 3.8: Fine Aggregate Was Weighted.

After that, the dry mix was put into a concrete mixer and thoroughly mixed while in dry condition. The water was added consistently into the mixer to achieve the desired w/c ratio. The mixing process was carried out until the mix is uniformly mixed.

Following that, a slump test was carried out to record the initial slump, as a control slump. To simulated delayed casting scenario, the fresh concrete was left in the mixer until the slump is 50mm as depicted in Figure 3.9. Slump tests were performed on regularly until this targeted value was reached, and then adding water or re-dosing SP were carried out as needed. After that, the concretet mix was remixed for 2 to 3minutes.

Figure 3.9: 50mm of Slump Was Measured.

After completing the mixing procedures, the fresh concrete was poured into the prepared 150mm×150mm×150mm cube molds. Before pouring, the molds were cleaned thoroughly with brush to remove any residue. A layer of oil was applied to the inner surface of the molds using a brush to facilitate easy demolding. Figure 3.10 shows the application of a thin oil layer on the mold's surface.

Figure 3.10: A Thin Layer of Oil Was Coated on the Mould's Surface.

Subsequently, the specimens were left to harden overnight, and the curing process continued for a period of 7 to 28 days. This procedure was repeated to prepare concrete mixes with varying dosages of superplasticizer, ranging from 0.1% to 0.7%.

3.4 Sieve Analysis (ASTM C136, 2014)

A sieve analysis is conducted to determine the particle size distribution of coarse and fine aggregates within a sample based on ASTM C136. This process establishes the aggregate gradation by analyzing the size distribution of particles after sieving. A standard 500 g oven-dried aggregate sample was placed on the tray as demonstrated in Figure 3.11. If the sample contained any lumps, these were gently crushed using a pestle and mortar to break the clumps, ensuring that the individual particles were not damaged.

Figure 3.11: Oven-Dried Aggregate Sample.

Following that, a series of test sieves were arranged in a stack on the shaker, with the largest sieve at the top and progressively smaller sieves below it. For fine aggregates, the sieves were set up as presented in Figure 3.12, with the largest sieve being 9.5 mm at the top and the smallest being 150 µm at the bottom.

Figure 3.12: Sieve Analysis Setup for Fine Aggregate.

Next, the 500 g sample was placed on the top sieve. To prevent fine particles from dispersing into the air, a sieve pan cover was placed over the stack.

The sieves were securely fastened onto the shaker machine. The shaker was powered on and allowed to run for 15 minutes, ensuring proper agitation without over-shaking, which could degrade the sample. After the shaking process, the particles retained on each sieve were weighed, and the percentage of the total sample weight passing through each sieve was calculated. This data provided insight into the particle size distribution of the aggregate by referring the grading requirements. Tables 3.1 and 3.2 present the grading requirements for fine and coarse aggragate according to ASTM C33.

Table 3.1: Grading requirements for fine aggregate (ASTM, 2016).

Sieve Size (mm)	Grading Requirements for Total Percent Passing by ASTM C33 (%)
9.5	100
4.75	95 to 100
2.36	80 to 100
1.18	50 to 85
0.6	25 to 60
0.3	5 to 30
0.15	0 to 10
Pan	-

Table 3.2: Grading requirements for coarse aggregate (ASTM, 2016).

Sieve Size (mm)	Grading Requirements for Total Percent Passing by ASTM C33 (%)
25	100
20	90 to 100
9.5	20 to 55
4.75	10 to 0
Pan	-

The aggregate weight retained in grams, the aggregate weight retained in percentage, and the cumulative proportion of coarser and finer particle grain were measured and computed. Equation 3.1 was used to calculate the fineness modulus of sand, and a graph showing the distribution of particle sizes was plotted.

$$FM = \frac{\Sigma\, TPR}{100} \tag{3.1}$$

where

FM = fineness modulus

$\Sigma\, TPR$ = summation of total percentage retained from the biggest size observed to and including sieve size 150 µm.

3.5 Curing

Curing is essential to improve the strength of freshly cast concrete. After one day of concrete casting, the curing process was carried out for all concrete specimen. At first, the specimen was demolded and clearly labeled according to the superplasticizer dosage. ASTM C31/C31M (2022) states that water should always be preserved on the concrete sample surfaces and the curing water temperature was maintained between 16 - 27 ˚C during curing. As noticed in Figure 3.13, the cubic specimens were cured in a water tank with a heavy cover.

Figure 3.13: Water Curing Process for the Concrete Specimens.

3.6 Concrete Test

There are several concrete test for both fresh concret properties and hardened concrete properties were conducted in ths study. The concrete test performed were including slump test, fresh density and air content test, Vee-Bee test, compacting factor test, hardened density test and compressive strength test.

3.6.1 Slump Test (ASTM C143, 2003)

The slump test was carried out in accordance with ASTM C143/C143M (2003) standards. For this approach, a metal truncated cone with dimensions of 300 mm in height, 100 mm in diameter at the top, and 200 mm in diameter at the bottom was used, coupled with a tamping rod that measured 16 mm in diameter and 600 mm in length. First of all, the mold was placed on a flat, moist and non-absorbent surface after being dampened. The operator stood on the two-foot sections to hold the mould in place while it was getting filled. The mould was filled in three layers, each making up approximately one third of the mould's total volume. Following each layer, the concrete was tamped using 25 equally distributed strokes of the tamping rod across the cross-section of the layer as shown in Figure 3.14.

Figure 3.14: Concrete Mix Was Tamped Using Tamping Rod.

As the concrete settled during the tamping step, additional concrete was poured to maintain an excess above the top of the mould. Excess concrete was removed from the surface after the top layer was compacted. The mould was then carefully removed by raising it vertically to a distance of 300 mm without causing any lateral or torsional movement. As specified by ASTM C143/C143M, the whole test completed within 2.5 minutes, from filling to mould removal. At last, a steel rod was positioned horizontally over the slump cone, extending over the slumped concrete, and the slump cone was then placed next to the concrete that had slumped. The slump value of the concrete was determined by measuring the vertical distance between the bottom of the steel rod and the specimen's displaced original centre as depicted in Figure 3.15.

Figure 3.15: Slump Value Was Determined.

3.6.2 Fresh density and Air Content Test (ASTM C138, 2008)

The test results for fresh density and air content complied with ASTM C138/C 138M (2008). A weighing scale, a tamping rod, and a cube mould were needed to carry out the test. Three nearly equal-volume layers of concrete were added to the container, and each layer was tamped 25 times with the tamping rod. Subsequently, the container was tapped to fill any voids formed by the tamping rod and to release any trapped large air bubbles. Extra concrete will be removed from the surface after a small quantity has been applied to cover up for any deficiencies. The outside of the mould was cleaned and weighed. Lastly, the weight of the empty cube mould was recorded, and Equation 3.2 was used to calculate the fresh density of the concrete.

$$D = \frac{W_c - W_m}{V_m} \quad (3.2)$$

where

D = Fresh density, kg/m^3

W_c = Weight of cube mould filled with concrete, kg

W_e = Weight of empty cube mould, kg

V_m = Volume of cube mould, m^3

By using the Equation 3.3, the air content of the concrete was calculated.

$$A = \frac{T - D}{T} \times 100 \quad (3.3)$$

where

A = Air content, %

T = Theoretical density of concrete computed on an air free basis, kg/m^3

D = Density of concrete, kg/m^3

3.6.3 Vebe Consistometer Test (ASTM C1170, 2008)

In compliance with ASTM C1170, a Vebe consistometer consisting of a vibrator table, a cylindrical mould, a slump cone, and a tamping rod were used to conduct the Vebe test. To determine the consistency of fresh concrete, this test measures the time taken for concrete to transform from a conical shape to a cylindrical shape under vibration, offering a quantifiable indication of workability. There were two components in the test, the first was a duplicate of the traditional slump test. In this first stage, the slump cone was placed within the consistometer's cylindrical container. Concrete was then poured into the cone in four layers, each layer being one-fourth of the cone's height. The concrete will be tamped 25 times with the tamping rod following the pouring of each layer as demonstrated in Figure 3.16.

Figure 3.16: Slumped Concrete in Cone Container.

Next, the stopwatch was started and the electrical vibrator was turned on simultaneously. The vibration was maintained until the surface of the concrete became horizontal and the concrete changed from having a conical to a cylindrical form. The Vebe consistency time will be represented as the elapsed time, rounded to the closest second. The Vebe time recorded reflects the consistency and workability of the concrete mix. A lower Vebe time indicates higher workability.

3.6.4 Compacting Factor Test (BS 1881, 1983)

BS 1881: Part 103 (1983) was followed to perform the compacting factor test. A compacting factor apparatus with two conical hoppers positioned above a cylinder, a tamping rod, a scoop, and a weighing scale were used in the test. The inside surfaces of the hoppers and cylinder were cleaned in order to ensure they were smooth and free of excess moisture before the test. The upper hopper was then gradually filled with a concrete sample using a scoop until it reached the rim. To let the concrete fall into the lower hopper, the trapdoor at the bottom of the top hopper was opened as presented in Figure 3.17.

Figure 3.17: Compacting Factor Test Apparatus.

The bottom hopper's trapdoor was opened after the concrete came to a rest so that it could fall into the cylinder below. The outer surface of the cylinder was cleaned and whatever excess concrete above it was removed. The cylinder containing the concrete was then weighed to the closest ten grams and recorded as the weight of partially compacted concrete. Subsequently, the cylinder was emptied and refilled with a same concrete mixture in six roughly equal layers. To attain full compaction, a tamping rod was used to compact each layer. Following the top layer's compacting, the cylinder's outside was cleaned and the top surface smoothed. The weight of the fully compacted concrete was then determined by weighing the concrete-filled cylinder to the closest 10 g. At last, the empty cylinder's weight was identified, and Equation 3.4 was utilized to calculate the compacting factor.

$$Compacting\ Factor = \frac{W_p - W_c}{W_f - W_c} \tag{3.4}$$

where

W_p = Weight of partially compacted concrete, g

W_f = Weight of fully compacted concrete, g

W_e = Weight of empty cylinder, g

3.6.5 Hardened Density Test

To determine the density of hardened concrete cube specimens according to ASTM C642, the specimens were first cured and allowed to reach the desired age. Surface moisture was then removed by gently wiping the specimens with a towel to achieve a surface-dry condition. As shown in Figure 3.18, the surface-dried specimens were weighed using a precise balance, and this mass was recorded as W_{dry}. The dimensions of the cubes were measured by using vernier caliper as iluustrated in Figure 3.19, and Equation 3.5 was utilized to calculate the hardened density.

Figure 3.18: Dimension of Cube Specimen Was Measured by using Vernier Caliper

Figure 3.19: Weight of Cube Specimen Was Measured.

$$Density = \frac{W_{dry}}{V} \tag{3.5}$$

where

W_{dry} = Weight of hardened concrete, g

V = Volume of cube specimen, g

3.6.6 Compressive Strength Test (BS EN 12390-3)

Using a compression testing machine, the compression test was performed in compliance with BS EN 12390-3 (2019). The cubic specimens were taken out of the water tank and oven dried to remove any remaining water from their surfaces after the specified curing time. A digital weighing scale and a vernier caliper were used to measure and record their dimensions and weight, respectively. The surfaces of the cubic specimens and the bearing surface of the testing machine were properly cleaned to get rid of any loose grit or unwanted material in order to ensure accuracy. The test was performed using the universal compression testing machine with a loading rate of 5 kN/s. In order to guarantee that the load is applied perpendicularly to the casting direction, each cubic specimen's center was positioned so that it aligned with the machine's base plate. At last, the concrete specimens were subjected to an axial force that increased gradually and at a steady pace until failure as illustrated in Figure 3.20.

Figure 3.20: Compressive Stregnth Test.

Equation 3.6 was used to calculate the specimens' compressive strength after the maximum load that they could withstand was recorded.

$$f_c = \frac{F}{A_c} \tag{3.6}$$

where

f_c = compressive strength, MPa

F = maximum load at failure, N

A_c = cross-sectional area of specimen on which the compressive force acts, m^2

3.7 Summary

This chapter provides a comprehensive overview of the study process, detailing each step from raw material preparation to testing methodologies. The experiment was carried out in two phases: the trial mix and the actual mix. In the trial mix phase, the focus was on identifying the optimal water-to-cement (w/c) ratio that would achieve a minimum compressive strength of 30 MPa after 28 days. A trial mix was prepared without any additional admixtures or extra water, serving as the control. The raw materials, including Ordinary Portland Cement (OPC), fine and coarse aggregates, and water, were carefully sourced and prepared. Based on the results from the trial mix, proportions for the actual mix were determined to ensure a consistent w/c ratio. The mixing process followed ASTM standards, emphasizing accurate measurement and uniform distribution of materials. During this phase, various tests were conducted according to ASTM or BS EN standards, such as slump tests, fresh density and air content tests, Vebe tests, compacting factor tests, hardened density tests, and compressive strength tests. The curing period for the specimens varied, with some cured for 7 days and others for 28 days. The experiment also included water addition and multiple dosages of superplasticizer, from 0.1% to 0.7% with 0.1% increment to evaluate their effects on concrete properties. All results and data from both fresh and hardened concrete tests were recorded and analyzed.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and discussion of the study. The optimum mix proportion determined from the trial mix was used to cast normal weight concrete samples with varying dosages of a LRSP in the actual mix. The discussion focuses on the relationship between workability and compressive strength for normal weight concrete with SP dosages ranging from 0% to 0.7% under delayed casting. An important aspect of this study involves redosing the SP to restore the original slump of the concrete, which was evaluated alongside the fresh and hardened concrete properties for each SP dosage. Additionally, the compressive strength of the normal weight concrete, incorporating SP, was assessed after 7 and 28 days of water curing. The chapter concludes with a comparison of the results to determine the optimal dosage of the LRSP.

4.2 Sieve Analysis

The sieve analysis was conducted to determine the particle size distribution of both fine and coarse aggregates used in normal weight concrete, since the proper gradation of aggregates is key to achieving the desired density, strength, and durability for concrete. Sieve sizes ranging from 9.5 mm to 150 μm were arranged in descending order, and the mass of aggregate retained on each sieve was measured and recorded. The percentage retained on each sieve was then calculated, followed by the computation of the cumulative percentage of finer particles passing through each sieve, as shown in Tables 4.1 and 4.2. The results were plotted on a logarithmic scale, as depicted in Figures 4.1 and 4.2. The plots confirmed that all finer passing percentages fall within the ASTM C33 (2013) specified ranges, indicating that both fine and coarse aggregates are well-graded and suitable for normal weight concrete.

The fineness modulus (FM) of the fine aggregate was calculated to assess its fineness, with the result being 2.96. According to ASTM C33 (2013), the FM should fall within the range of 2.1 to 3.1, making the obtained value of

2.96 well within the acceptable range. This FM value indicates that the average particle size of the fine aggregate lies between the 2nd and 3rd sieves (4.75 mm and 2.36 mm). A higher FM value suggests coarser aggregate, while a lower value indicates finer aggregate. The proper distribution of sand particle sizes, as evidenced by this FM value, is crucial as finer particles fill gaps between coarser particles, contributing to the density and workability of the concrete mix, and ensuring minimal air gaps and a dense concrete matrix, which is essential for normal weight concrete.

Table 4.1: Cumulative Percentages of Fine Aggregate Sample.

Sieve Size (mm)	**Cumulative Percentage (%)**		**Grading Requirements for Total Percent Passing by ASTM C33 (%)**
	Coarser	**Finer**	
9.5	0.00	100.00	100
4.75	0.00	100.00	95 to 100
2.36	5.36	94.64	80 to 100
1.18	33.93	66.07	50 to 85
0.6	67.86	32.14	25 to 60
0.3	91.07	8.9	5 to 30
0.15	98.21	1.79	0 to 10
Pan	100.00	0.00	-

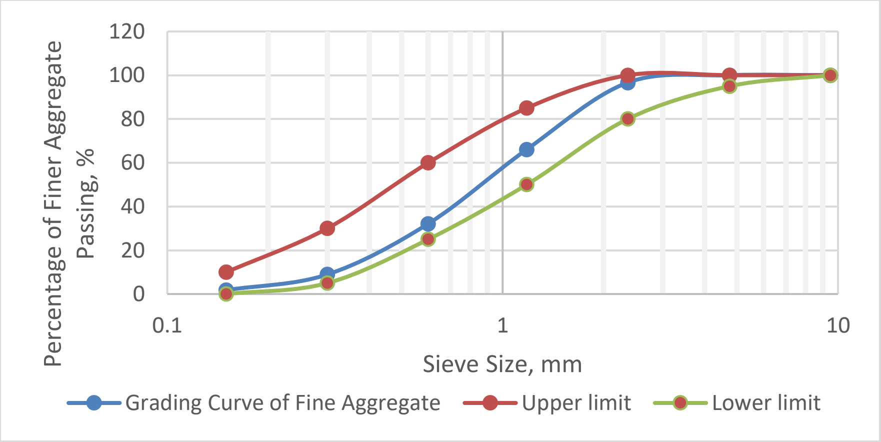


Figure 4.1: Grading Curve of Fine Aggregate.

Additionally, the coarse aggregate was also found to meet the ASTM C33 standards for coarse aggregates. The fineness modulus for coarse aggregate is 1.67. The well-graded coarse aggregate will form a strong skeleton within the concrete, providing the necessary strength and structural integrity. Hence, the compatibility between the fine and coarse aggregates, both meeting ASTM C33 standards, ensures a good interlocking matrix in the normal weight concrete.

Table 4.2: Cumulative Percentages of Coarse Aggregate Sample.

Sieve Size (mm)	**Cumulative Percentage (%)**		**Grading Requirements for Total Percent Passing by ASTM C33 (%)**
	Coarser	**Finer**	
25	0.00	100.00	100
20	5.38	94.62	90 to 100
9.5	63.44	36.56	20 to 55
4.75	97.85	2.15	10 to 0
Pan	100.00	0.00	-

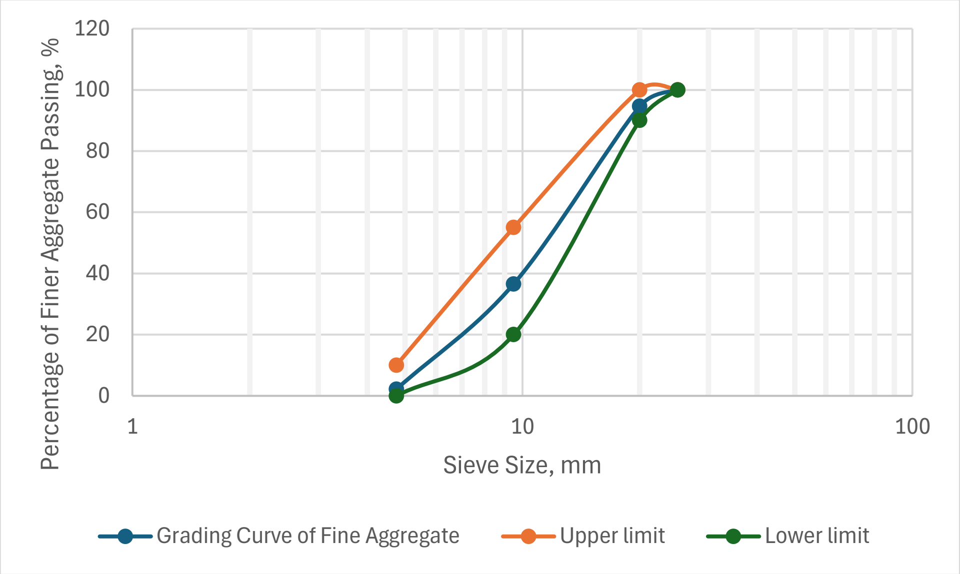


Figure 4.2: Grading Curve of Coarse Aggregate.

4.3 Trial Mix

An outline of the trial mixes is given in this section, the purpose of the trial mix procedure was to find the ideal mix ratios such that the concrete samples would meet the goal 30 MPa compressive strength and 100±25 mm slump range. Water, fine aggregates, coarse aggregates, and OPC are the components of the control mix. The selected optimum concrete mix proportion will be applied to the actual mix, where the concrete will experience delayed casting, followed by water addition and re-dosing of the superplasticizer (SP).Table 4.3 provided the mix proportions used in the trial mixes.

Table 4.3: Mix Proportions of Trial Mix.

Specimen	**W/C ratio**	**Unit weight of Material, kg /m^3**				
		Cement	**Water**	**Fine Aggregate**	**Coarse Aggregate**	
					10mm	**20mm**
A	0.5	350	175	693.75	393.75	787.5
B	0.6	350	210	680.8	386.4	772.8
C	0.63	340	215	650	1195	
D	0.63	340	215	789	1056	
E	0.65	350	227.5	455.63	455.63	911.25
F	0.65	315	204	602	1279	
G	0.66	350	231	691.22	375.93	751.85
H	0.7	350	245	451.25	451.25	902.5
I	0.7	350	245	667.85	379.05	758.1
J	0.7	321	224.7	556.29	432.67	865.34

4.3.1 Slump Test

Slump Test was carried out to ensure the slump value is within 100±25 mm slump range, the trial mix result that not fall within the range indicate that the mix proportion is not suitable. Hence, the w/c ratio and fine aggregate content are adjusted to achieve the targeted slump range as shown in Figure 4.3.

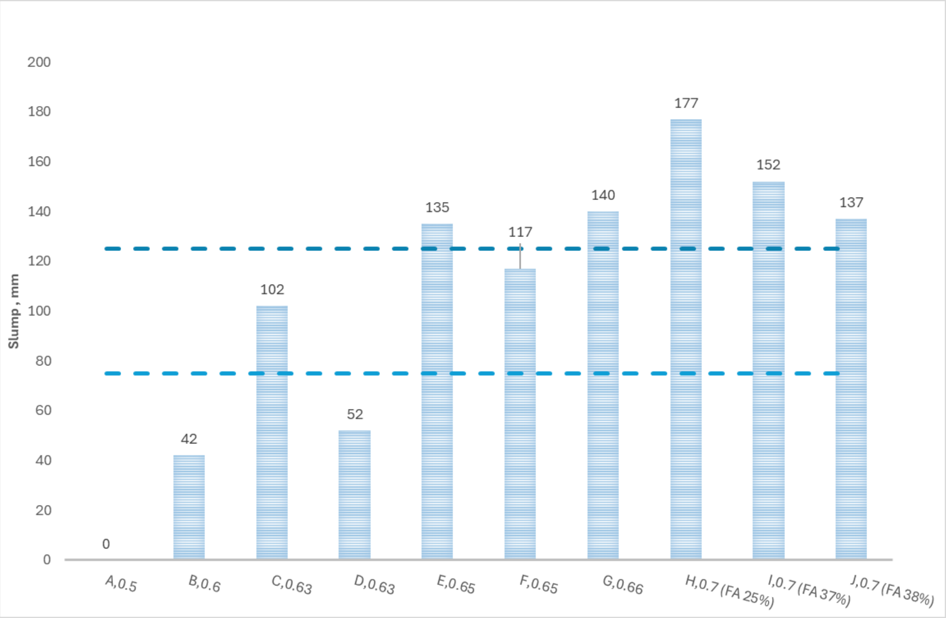


Figure 4.3: Slump Value againt Concrete Mix for Trial Mix.

Based on Figure 4.3, there is a trend where increasing the water-cement ratio leads to higher slump values, indicating a more workable and fluid concrete mix. This is due to higher water content will increase the interparticle lubrication. According to Figure 4.3, it indicates that Specimen H, I, and J have 25%, 37% and 38% of fine aggregate contents repestively, as the fine aggregate percentages increase, the slump values decrease by increasing the mix's cohesion, resulting in a stiffer, less fluid mix. Since, finer particles require more water to wet their larger specific surface. Among the specimens, only Specimen C and F achieve slump values of 102 mm and 117 mm respectively, both of which fall within the targeted slump range of 75 to 125 mm.

4.3.2 Compressive Strength Test

The trial mixes of cubic concrete specimens were prepared and cured for both 7 and 28 days with water-cement ratios ranging from 0.50 to 0.70. Appendix D presents the compressive strength test results for these trial mixes. The optimal mix which achieves a characteristic strength of at least 30 MPa at 28 days will be selected. If the concrete fails to reach the targeted strength at 28 days, an adjustments will be needed, such as lowering the w/c ratio or modifying the aggregate content. While increasing the w/c ratio can improve workability, excessive water leads to higher porosity, which significantly reduces compressive strength. Similarly, the compressive strength generally improves with a higher fine aggregate content, but only up to an optimal point; beyond that, too many fines can hinder the interlocking of coarse aggregates and reduce strength.

As shown in Figure 4.4, Specimens C, F, and J achieved 28 days compressive strengths of 31.9 MPa, 30.35 MPa, and 30.22 MPa respectively, all meeting the required strength criteria. Since, Specimen C had the highest compressive strength at 31.9 MPa, hence the mix proportion for Specimen C is used for further experimentation, including the delayed casting, re-dosing of SP and water addition.

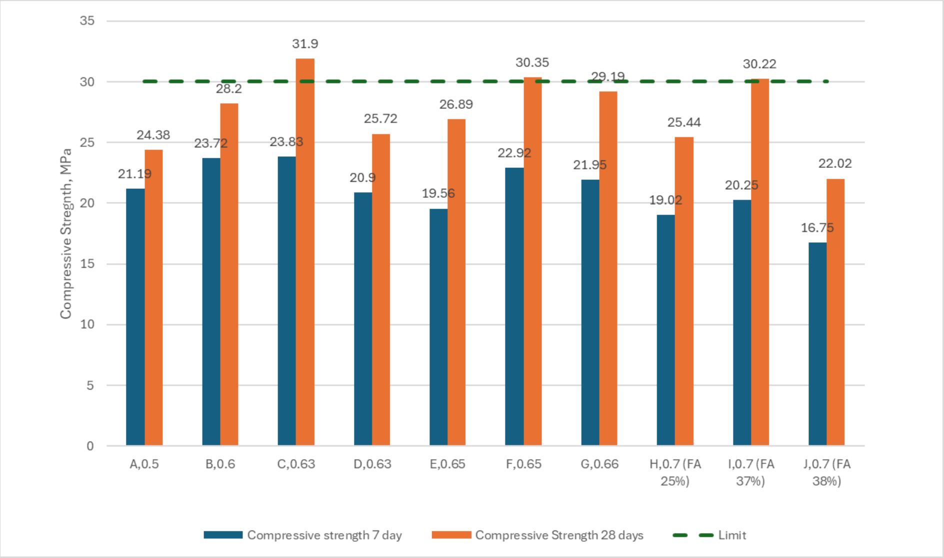


Figure 4.4: Compressive Strength of Trial Mixes for 7 and 28 Days of Curing Period against w/c Ratio.

4.3.3 Summary

Based on the trial mix results, Specimen C was selected as the control mix for the actual concrete mix due to its optimal performance in both slump and compressive strength tests. Specimen C, with a W/C ratio of 0.63, achieved a slump value of 102 mm, which falls within the target range of 100 ± 25 mm. Additionally, it demonstrated the highest 28-day compressive strength of 31.9 MPa, meeting the minimum requirement of 30 MPa.

4.4 Actual Mix

This chapter presents the results from tests conducted on both the fresh and hardened properties of concrete. It also provides an analysis of the relationships between untreated concrete, delayed casting concrete, concrete with added water, and concrete re-dosed with a low-range superplasticizer. The superplasticizer was applied in doses ranging from 0.1% to 0.7%, increasing by 0.1% increments. Based on the results, the optimal dosage of the superplasticizer was determined.

4.4.1 Mix Proportion

Table 4.4 shows the mix proportion for the normal weight concrete in the actual mix.

Table 4.4: Mix Proportions of Actual Mix.

Specimens	**w/c ratio**	**Unit weight of Material, kg /m^3**				**SP, %**
		Cement	**Water**	**Fine Aggregate**	**Coarse Aggregate**	
C	0.63	340	215	650	1195	-
C(D)	0.63	340	215	650	1195	-
C(W)	0.63	340	215	650	1195	-
SP0.1	0.63	340	215	650	1195	0.1
SP0.2	0.63	340	215	650	1195	0.2
SP0.3	0.63	340	215	650	1195	0.3
SP0.4	0.63	340	215	650	1195	0,4
SP0.5	0.63	340	215	650	1195	0.5
SP0.6	0.63	340	215	650	1195	0.6
SP0.7	0.63	340	215	650	1195	0.7

Ordinary Portland Cement (OPC), water, fine aggregates, and coarse aggregates were used in the mix proportions for the actual concrete mixes. The w/c ratio for all design mixes was consistently set at 0.63. In the control mix (C), the target slump was 100±25 mm achieved without any admixtures. For the delayed casting mix (C(D)), the concrete was left in the mixer for 20 to 30 minutes after mixing, allowing the slump to reduce to 50 mm. The water addition mix (C(W)) underwent the same delay, after which additional water was added to restore the original slump to 100 mm. Additionally, superplasticizer (SP) was incorporated into the design mixes SP0.1 through SP0.7, with dosages ranging from 0.1% to 0.7% by weight of cement under delayed casting condition.

4.5 Fresh Concrete Properties

The fresh concrete properties, including slump, vebe time, compacting factor tests, and fresh density and air content were evaluated. The results of slump test, vebe consistometer test, compacting factor, and fresh density and air content were tabulated in Appendix E, F, G and H respectively.

4.5.1 Slump

In this study, the slump test was conducted to the workability of concrete under delayed casting, water addition and re-doing with SP conditions as illustrate in Figure 4.5.

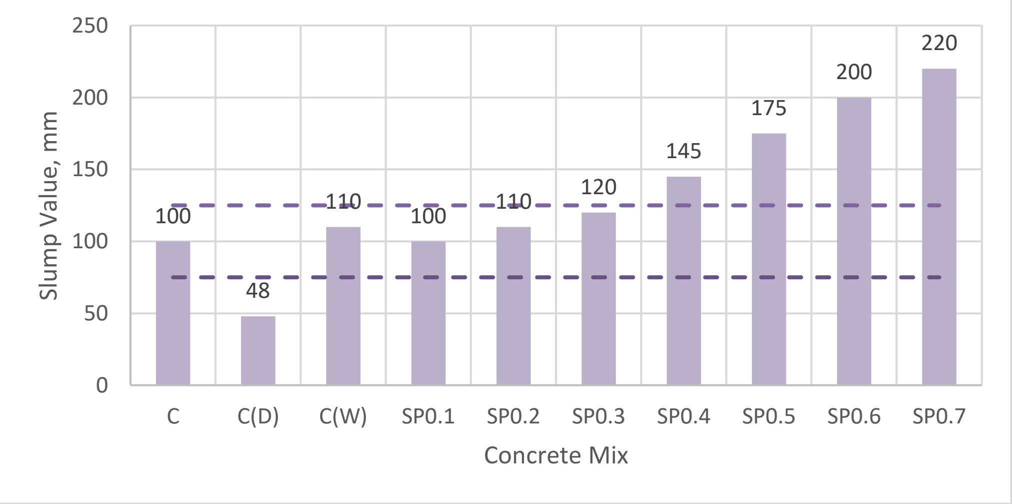


Figure 4.5: Slump against Concrete Mix.

As shown in Figure 4.5, the slump of C(D) decreased by 51% compared to the control mix, likely due to reduced water content and hence resulting in lower workability. Following that, the slump regain to original slump of 110mm by adding 250ml water in to theconcrete mix after slump drop to 50mm. In the case of the concrete mix C(W), adding 250ml of water restored it to the original 110mm after the slump dropped to 50mm. This adjustment enhanced the workability of the mix, compensating for the loss of fluidity and helping to regain the desired slump.These findings shows similar trend found by Mahzuz et al. (2020).

According to Figure 4.5, it indicates that the slump value increased as the dosage of SP increased and SP0.7 has the highest slump value. These results can be explained by the fundamental mechanisms through which superplasticizers improve concrete workability. The initial reduction of slump to 50 mm is a result of the ongoing hydration process and the loss of free water in the mix. When the superplasticizer is redosed, it reactivates the dispersion of cement particles through electrostatic repulsion and steric hindrance. The superplasticizer molecules adsorb onto the cement particles, imparting a negative charge that causes the particles to repel each other. This repulsion breaks up the flocculated particles, releasing trapped water and increasing the fluidity of the mix, which is reflected in the regained slump values. Additionally, the steric hindrance provided by the long polymer chains of the superplasticizer further prevents the cement particles from coming too close to each other, maintaining their dispersion and enhancing the mix’s workability (Aicha, 2020). As a result, the concrete can achieve a significant regain in slump after redosing, as seen in the data.

The data suggests the need for caution when using higher dosages of superplasticizer. As shown in Figure 4.6, a collapsed slump occurred at 220mm for the SP0.7 mix. According to Alsadey (2012), excessive dosage of admixtures can lead to significant slump loss, thereby preventing the achievement of the desired true slump. Additionally, both SP0.6 and SP0.7 displayed clear signs of segregation and bleeding, as illustrated in Figures 4.7 and 4.8. The separation between the aggregates and cement paste is evident, with the heavier aggregates settling at the bottom and the lighter, more fluid cement paste and water rising to the top. This uneven distribution indicates segregation, where the components of the mix are not uniformly distributed. These observations highlight the risks associated with overdosage of superplasticizer, as both segregation and bleeding can compromise the uniformity and strength of the concrete, as disccused by Alsadey (2012).

C(D) (48mm Slump)

SP0.7 (220mm Collapse Slump)

Figure 4.6: Slump Under Delayed Casting and Re-Dosing with 0.7% of SP.

Figure 4.7: Concrete Mix Condition for SP0.6.

Figure 4.8: Concrete Mix Condition for SP0.7.

4.5.2 Vebe Time

Figure 4.9 presents the results of the Vebe Consistometer Test, which measures the Vebe time (in seconds) for various concrete mixes. The Vebe time is an indication of the workability and consistency of the concrete, with longer times typically suggesting stiffer mixes that require more effort to compact.

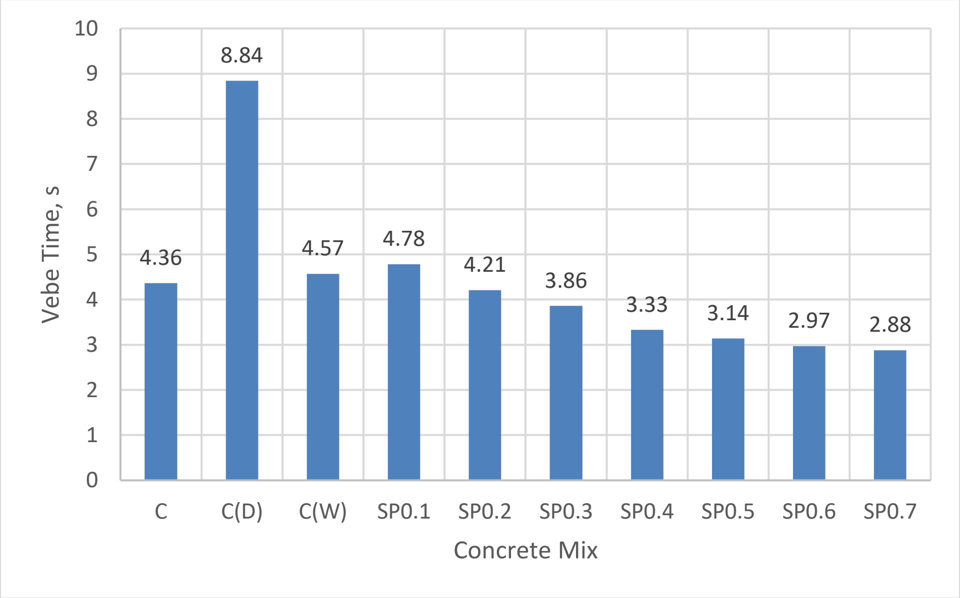


Figure 4.9: Vebe Time against Concrete Mix.

The delayed casting significantly increased the Vebe time to 8.84 seconds, as shown in Figure 4.9, due to the stiffening of the concrete over time. The workability decreased from medium to low levels, which is not ideal for reinforced concrete (Gharpedia, 2024; Neville, 2011). This result aligns with expectations, indicating that delayed casting reduces concrete workability. Although adding 250ml of water to mix C(W) restored the original workability by improving fluidity, this method has drawbacks. Increasing the water content raises the water-cement ratio, which may reduce the concrete strength.

Based on Figure 4.9, the addition of superplasticizer significantly improved the workability of the concrete, as indicated by a reduction in Vebe time of approximately 45% to 67%. This decrease in Vebe time is attributed to the chemical action of the superplasticizer, which enhances the dispersion of cement particles, lowers the mixture's viscosity, and allows it to flow more easily. The data showed that adding 0.2% superplasticizer (SP0.2) restored the workability of the concrete, reducing the Vebe time to 4.21 seconds. This redosing of 0.2% superplasticizer was just enough to restore workability and provided a slight improvement in overall performance.

4.5.3 Compacting Factor

Figure 4.10 presents the results of the Compacting Factor Test, providing insight into how delayed casting, water addition, and superplasticizer dosages influence the workability of concrete. The degree of compaction, known as the compacting factor, is quantified by the density ratio. This ratio compares the density of partially compacted concrete to the density of fully compacted concrete, providing a measure of the mix's workability and its ability to achieve proper compaction under standard conditions.

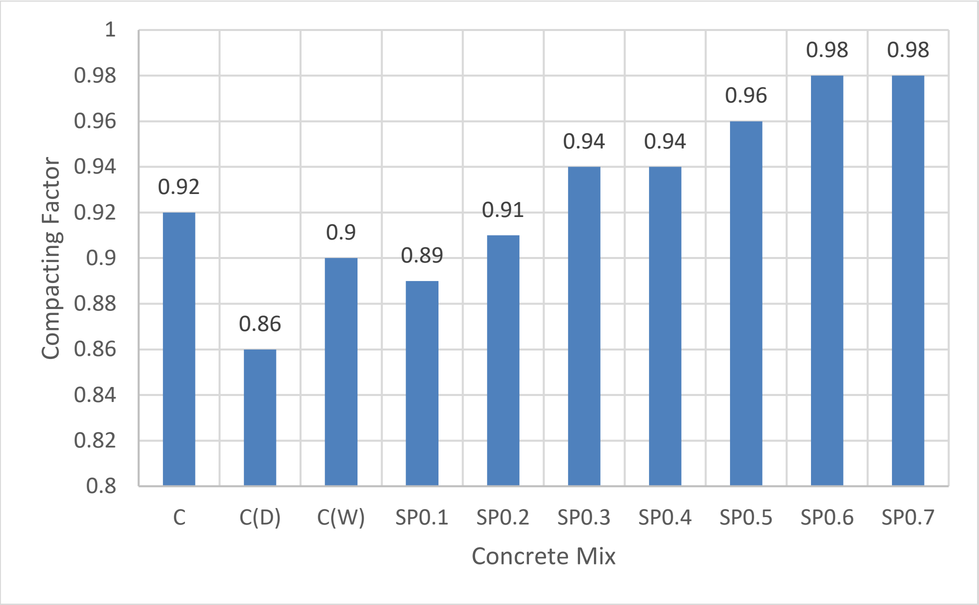


Figure 4.10: Compacting Factor against Concrete Mix.

There was a significant decrease in the compacting factor from 0.92 to 0.86 due to delayed casting, indicating a clear reduction in workability as indicated in Figure 4.10. This decline can be attributed to the concrete stiffening, which increases internal resistance and demands more energy for compaction. Adding water to the delayed mix improved the compacting factor to 0.90, indicating a partial recovery of workability. However, raising the water-cement ratio could negatively affect the concrete's long-term strength and durability.

To address the diminished workability from delayed casting, water was added to the delayed mix (C(W)), which improved the compacting factor to 0.90. While this adjustment partially recovered the workability, it also increased the water-cement ratio. Elevated water content can adversely affect the concrete's long-term strength and durability by promoting higher porosity and potential segregation of aggregates.

In contrast, re-dosing the delayed mix with varying dosages of superplasticizer (SP) demonstrated a clear and consistent improvement in compacting factors. Starting with SP0.1, the compacting factor was 0.89, which progressively increased with higher SP dosages: SP0.2 (0.91), SP0.3 (0.94), SP0.4 (0.94), SP0.5 (0.96), SP0.6 (0.98), and SP0.7 (0.98). This upward trend underscores the effectiveness of superplasticizers in enhancing concrete workability without the negative implications associated with increased water content. These results are consistent with Dumne (2014), who reported significant enhancements in workability and compacting factors with increasing superplasticizer dosages. This alignment reinforces the reliability of superplasticizers as a preferred additive for maintaining optimal concrete performance under delayed casting conditions.

4.5.4 Fresh Density and Air Content

The fresh density, which indicates the mass per unit volume of the concrete immediately after mixing, was calculated and then divided by the theoretical density, 2400kg/m^3 to derive the air content present within the mix. Figure 4.11 shows the results of fresh density and air content.

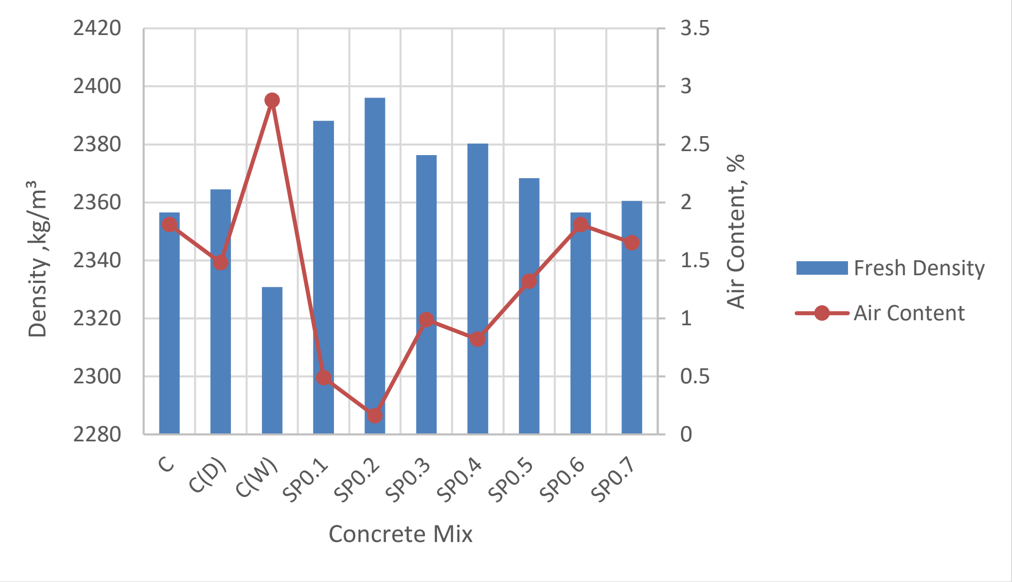


Figure 4.11: Fresh Density and Air Content.

Contrary to initial expectations, the delayed control mix (C(D)) exhibited a slight increase in density (approximately 0.34%**)** compared to the control mix (C), which had a density of 2356.54 kg/m³**.** This marginal increase suggests that the casting delay did not adversely affect the concrete's density as initially hypothesized. Instead, it may indicate a minor compaction or settling effect during the delay period. Subsequent addition of water to the delayed mix (C(W)) resulted in a decrease in density of approximately 1.47% compared to the delayed control mix (C(D)), reducing the density to 2330.86 kg/m³**.** This reduction can be attributed to the increased water content, which likely led to higher porosity and potential segregation of aggregates, thereby lowering the overall density of the concrete mixture.

In terms of air content, the delayed control mix (C(D)) demonstrated a decrease of approximately 18.23% compared to the control mix (C), reducing the air content from 1.81% to 1.48%**.** This significant reduction suggests that the casting delay may have facilitated better compaction or reduced entrapped air within the mixture, thereby enhancing its overall density. Conversely, the addition of water to the delayed mix (C(W)) resulted in a substantial increase in air content by approximately 94.59%**,** raising the air content to 2.88% compared to 1.48% in C(D). This substantial rise in air content can lead to higher porosity, which may adversely affect the concrete's mechanical properties and long-term durability.

Figure 4.11 illustrates the impact of varying superplasticizer (SP) dosages on the fresh density and air content of concrete mixtures. It shows that SP0.2 attains the highest density with the lowest air content. As the SP dosage increases from SP0.1 to SP0.2, there is a notable increase in fresh density from 2388.15 kg/m³ to 2396.05 kg/m³, accompanied by a significant decrease in air content from 0.49% to 0.16%. This enhancement in density and reduction in air content can be attributed to the optimal dispersion of cement particles facilitated by the superplasticizer, which promotes better particle packing and minimizes entrapped air within the mixture. However, as the SP dosage continues to rise beyond SP0.2, a gradual decline in density is observed, decreasing to 2356.54 kg/m³ at SP0.6 before slightly increasing to 2360.49 kg/m³ at SP0.7. Concurrently, air content begins to rise from 0.16% at SP0.2 to 1.81% at SP0.6, before slightly decreasing to 1.65% at SP0.7. This trend indicates that excessive dosages of superplasticizer lead to increased air entrainment and potential segregation, which adversely affect the concrete's density and introduce higher porosity.

4.6 Hardened Concrete Properties

The hardened concrete properties, including hardened density and compressive strength were evaluated. The results of hardened density and compressive strength test were tabulated in Appendix I and J respectively.

4.6.1 Hardened Density

It indicates that the hardened density of the control mix (C) is the highest, with a slight increase from 2402.02 kg/m³ at 7 days to 2405.92 kg/m³ at 28 days as shown in Figure 4.12 below. This is followed by C(D) and SP0.2. In contrast, the C(W) mix exhibits the lowest density, though it shows an increase from 2338.31 kg/m³ at 7 days to 2346.79 kg/m³ at 28 days. The density of the hardened concrete is consistently higher than its fresh density across all mixes. This trend is consistent with findings by Mehta and Monteiro (2014), who reported that hardened concrete typically has a higher density compared to its fresh state due to the ongoing hydration and consolidation processes during curing. As concrete cures, additional hydration of the cement particles occurs, which helps to fill voids and increase the overall density (Neville, 2011). Despite these increases, the changes in density from the fresh state to the hardened state are relatively minor. This suggests that while the curing process contributes to some density gain, it does not cause significant variations in the overall density of the concrete mixes. The minimal changes observed are in line with the observations of Chandra and Berntsson (2002), who noted that factors such as the initial mix proportions, type and amount of additives, and specific curing conditions play a crucial role in the density variations of concrete.

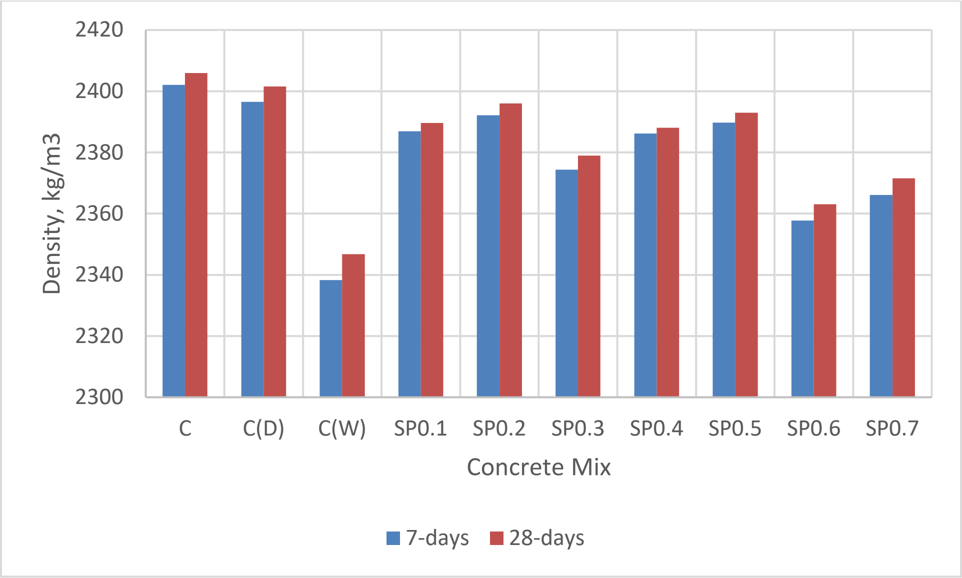


Figure 4.12: Hardened Density at 7 and 28 Days of Curing Period

4.6.2 Compressive Strength

In this project, 100 mm x 100 mm x 100 mm cubic-shaped concretes with different dosage of SP ranging from 0.1 % - 0.7 % with an interval of 0.1 % were cast. After being water cured for 7 and 28 days, these samples are tested for a compressive test. The compressive strength of the specimens was calculated from the average of three cracked cubic samples. The compressive strength test results for 7 days and 28 days curing ages are shown in Figure 4.13. It can be observed that the compressive strength increased as the curing age progressed. According to Neville (2011), they found that the compressive strength of concrete improves as the curing duration extends, due to continued hydration and the development of a more cohesive microstructure.

Figure 4.13: Graph of Compressive Strength against Concrete Mix.

Based on Figure 4.13, the delayed casting mix (C(D)) had a lowest compressive strength, starting at 17.30 MPa at 7 days and reaching 23.52 MPa at 28 days. This represents a reduction of approximately 26.4% in strength at 28 days compared to the control mix. The lower strength in C(D) can be attributed to the delays in casting, which likely impacted the hydration process and the development of the concrete’s microstructure. Delayed casting can lead to hardened concrete and the formation of honeycombing, which subsequently reduces strength. Furthermore, when comparing C(D) with the water-added mix (C(W)), the latter also showed a decrease in compressive strength. C(W) had a compressive strength of 16.63 MPa at 7 days and 22.07 MPa at 28 days, which is about 9.3% lower at 28 days compared to C(D). The reduction in strength in C(W) may be due to the excess water diluting the cement paste and weakening the concrete matrix.

The results for the superplasticizer (SP) dosages reveal that compressive strength generally increased with higher dosages up to SP0.5, where the peak strength was observed at 25.46 MPa at 7 days and 32.41 MPa at 28 days. However, beyond this optimal dosage, specifically at SP0.6 and SP0.7, the compressive strength began to decline. SP0.6 recorded strengths of 23.07 MPa at 7 days and 29.74 MPa at 28 days, while SP0.7 showed 22.27 MPa at 7 days and 28.03 MPa at 28 days. Furthermore, SP0.2 just achieve the desired compressive strength of 30MPa at 28days. As shown in Figure 4.13, there are different behaviour on compressive strength under different dosage of superplasticizer, which similar with the finding from Alsadey (2015). At very low dosage addition of superplasticizer not able to increase the compressive strength of concrete, on the other hand, the superplasticizer, increase in dosage will increase the compressive strength. Since addition of superplasticizer will provide more water for concrete mixing, not only the hydration process will not be disturbed, but, it is accelerated by the additional water from deflocculation of cement particles. Hence, increase in dosage will increase the entrapped water and promote hydration of cement.Though increment in dosage of admixture will enhance the compressive strength, there is still an optimum limit for the usage of admixture. When the dosages go beyond this limit, increase in dosage will only reduce the compressive strength. This phenomenon occur since over dosage of superplasticizer will cause bleeding and segregation, which will affect the cohessiveness and uniformity of the concrete. As a result, compressive strength will reduce if the used dosage is beyond the optimum dosage.

Figure 4.14 shows the failure pattern of concrete mix from SP0.1 to SP0.7. The failure patterns across different superplasticizer dosages suggest a direct correlation between the dosage and the concrete's ability to withstand compressive forces. At lower dosages (SP0.1 - SP0.4), the failure seems to follow a typical brittle failure pattern with sudden cracking and breaking, indicating that the concrete may not be adequately plasticized. As the dosage increases to SP0.5 - SP0.7, the failure patterns start to exhibit more ductility, likely due to the enhanced flowability and reduced water content in the mix. However, excessive superplasticizer (above SP0.6) could lead to over-saturation, reducing overall strength despite the improved workability.


SP0.1
SP0.5
SP0.2
SP0.6
SP0.3
SP0.7
SP0.4

Figure 4.14: Failure Pattern of Cube Specimen.

4.7 Optimum Dosage

Based on the investigation of both fresh and hardened concrete properties, SP0.2 was identified as the optimum dosage of superplasticizer. This dosage yielded a slump value of 110 mm, which is well within the targeted slump range of 100±25 mm, even after undergoing delayed casting. Across all workability tests, including the Vebe consistometer test, compacting factor test, and slump test, SP0.2 exhibited a medium degree of workability, consistent with that of the control mix we aimed to regain. In terms of compressive strength, SP0.2 achieved a strength of 30.69MPa at 28 days, exceeding the desired strength benchmark of 30 MPa. This demonstrates that SP0.2 offers an ideal balance between workability and strength, ensuring consistent performance in both fresh and hardened states.

4.8 Summary

In this study, the effects of delayed casting on the slump behavior and compressive strength of Grade 30 concrete were examined following re-dosing with low-range superplasticizer and water addition. It was observed that delayed casting (C(D)) led to a reduction in both workability and compressive strength. While water addition (C(W)) restored workability, it compromised compressive strength. When re-dosed with superplasticizer, workability improved with increasing dosages from SP0.1 to SP0.7, but the compressive strength exhibited a different trend, peaking at SP0.2 and SP0.5 before declining due to overdosing. The optimum dosage was identified at SP0.2, achieving a slump of 110 mm and a compressive strength of 30.69 MPa. At this dosage, the concrete mix, even after delayed casting, regained the targeted slump range of 100±25 mm and met the designed compressive strength of 30 MPa.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In summary, this research investigated the impact of varying dosages of low-range superplasticizer (SP) on regaining the original slump of Grade 30 concrete after delays in casting. Three main objectives were addressed. First, the study compared the fresh properties of untreated concrete, concrete treated with water addition, and concrete re-dosed with low-range superplasticizer. Fresh properties tests, including the slump test, Vebe consistometer test, compacting factor test, and tests for fresh density and air content, demonstrated that higher dosages of SP improved workability, while water addition also enhanced workability. However, excessive SP dosages compromised concrete cohesiveness.

Second, this study compared the hardened properties of these different concrete treatments, assessing hardened density and compressive strength. It was found that water addition led to reduced compressive strength, and excessive SP dosages also decreased strength, though varying the dosage showed different strength behaviors.

Finally, this study determined that a 0.2% dosage of low-range superplasticizer was optimal for restoring the original slump of Grade 30 concrete without compromising compressive strength.

This study is significant as it provides practical insights for optimizing concrete performance in real-world scenarios where delays in casting occur. By identifying the most effective dosage of superplasticizer for re-dosing, this research helps improve both the workability and structural integrity of concrete, which is crucial for maintaining quality and durability in construction projects.

5.2 Recommendations for future work

The following recommendations are proposed to refine study outcomes and enhance the reliability of the data, thereby improving future research efforts.

i. Explore the effects of both chemical and mineral admixtures by integrating different types into concrete mixtures to assess their combined impact on performance.
ii. Examine the concrete’s performance and durability over extended curing periods beyond 56 days. Assessing the long-term behavior can provide insights into changes in mechanical strengths and overall durability.
iii. Utilize scanning electron microscopy to gain a deeper understanding of the concrete's microstructure and morphology, providing more detailed insights into its composition and performance.
iv. Determine the depth of water penetration under pressure to evaluate the porosity of concrete treated with superplasticizer, which will help in understanding its impermeability and durability.

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APPENDICES

Appendix A: Sieve Analysis Result for Fine Aggregate.

Sieve Size (mm)	**Weight**				**Cumulative Percentage (%)**		**Grading Requirements for Total Percent Passing by ASTM C33 (%)**
	Empty sieve (kg)	**Seive + Aggregate Retained (kg)**	**Aggregate Retained on Each Sieve (kg)**	**Aggregate Retained on Each Sieve (%)**	**Coarser**	**Finer**	
9.5	0.44	0.44	0	0	0.00	100.00	100
4.75	0.49	0.49	0	0	0.00	100.00	95 to 100
2.36	0.47	0.5	0.03	5.36	5.36	94.64	80 to 100
1.18	0.37	0.53	0.16	28.57	33.93	66.07	50 to 85
0.6	0.34	0.53	0.19	33.93	67.86	32.14	25 to 60
0.3	0.37	0.5	0.13	23.21	91.07	8.9	5 to 30
0.15	0.37	0.41	0.04	7.14	98.21	1.79	0 to 10
Pan	0.25	0.26	0.01	1.79	100.00	0.00	-
	Total		0.56	100			

Appendix B: Sieve Analysis Result for Coarse Aggregate.

Sieve Size (mm)	Weight				Cumulative Percentage (%)		Grading Requirements for Total Percent Passing by ASTM C33 (%)
	Empty sieve (kg)	**Seive + Aggregate Retained (kg)**	**Aggregate Retained on Each Sieve (kg)**	**Aggregate Retained on Each Sieve (%)**	**Coarser**	**Finer**	
25	0.4	0.4	0	0.00	0.00	100.00	100
20	0.44	0.49	0.05	5.38	5.38	94.62	90 to 100
9.5	0.4	0.94	0.54	58.06	63.44	36.56	20 to 55
4.75	0.49	0.81	0.32	34.41	97.85	2.15	10 to 0
Pan	0.25	0.27	0.02	2.15	100.00	0.00	-
	Total		0.93	100			

Appendix C: Slump Test Result of Trial Mix.

Specimen	**Slump Value (mm)**			
	1	**2**	**3**	**Average**
A	0	0	0	0
B	40	42	45	40
C	150	152	145	150
D	180	177	170	180
E	130	135	140	130
F	140	140	135	140
G	120	117	110	120
H	50	52	55	50
I	110	102	105	110
J	140	137	145	140

Appendix D: Compressive Strength of Trial Mixes for 7 and 28 Days of Curing Period.

Specimen	**Compressive Strength (MPa)**							
	7 days				**28 days**			
	1	**2**	**3**	**Average**	**1**	**2**	**3**	**Average**
A	21.12	17.89	24.57	21.19	24.71	19.51	28.91	24.38
B	22.6	20.42	28.14	23.72	29.94	30.14	24.52	28.2
C	23.17	24.53	23.8	23.83	31.72	31.07	32.9	31.9
D	20.16	21.28	21.26	20.9	26.22	23.95	26.99	25.72
E	20.54	18.71	19.44	19.56	26.29	26.52	27.85	26.89
F	24.86	23.36	20.54	22.92	31.2	30.25	29.59	30.35
G	22.79	20.96	22.11	21.95	28.44	30.85	28.27	29.19
H	18.83	17.55	20.67	19.02	25.23	25.04	26.04	25.44
I	19.12	16.75	24.89	20.25	30.61	31.11	28.93	30.22
J	15.3	18.7	16.26	16.75	22.72	23.25	20.08	22.02

Appendix E: Slump Test Result of Actual Mix.

Specimen	**Slump Value (mm)**			
	1	**2**	**3**	**Average**
C	110	85	105	100
C(D)	50	55	40	48
C(W)	120	100	110	110
SP0.1	105	100	95	100
SP0.2	**120**	**110**	**100**	**110**
SP0.3	135	120	105	120
SP0.4	160	145	130	145
SP0.5	185	180	160	175
SP0.6	205	200	195	200
SP0.7	220	215	225	220

Appendix F: Vebe Consistometer Test Results.

Specimen	**Vebe Time, s**
C	4.36
C(D)	8.84
C(W)	4.57
SP0.1	4.78
SP0.2	4.21
SP0.3	3.86
SP0.4	3.33
SP0.5	3.14
SP0.6	2.97
SP0.7	2.88

Appendix G: Compacting Factor Test Results.

Specimen	Weight, kg					Compacting Factor
	Empty Cylinder	Cylinder + Partially Compacted Concrete	Cylinder + Fully Compacted Concrete	Partially Compacted Concrete	Fully Compacted Concrete	
C	2.76	13.48	14.46	10.72	11.7	0.92
C(D)	2.76	12.54	14.16	9.78	11.4	0.86
C(W)	2.76	13.14	14.26	10.38	11.5	0.90
SP0.1	2.76	13.06	14.32	10.3	11.56	0.89
SP0.2	2.76	13.12	14.42	10.36	11.66	0.91
SP0.3	2.76	14.01	14.73	11.25	11.97	0.94
SP0.4	2.76	14.15	14.82	11.39	12.06	0.94
SP0.5	2.76	14.22	14.74	11.46	11.98	0.96
SP0.6	2.76	14.26	14.48	11.5	11.72	0.98
SP0.7	2.76	14.4	14.68	11.64	11.92	0.98

Appendix H: Fresh Density and Air Content.

Specimen	**Sample**	**Weight (kg)**		**Volume of Mould (m^3)**	**Fresh Density (kg/m^3)**	**Average Fresh Density (kg/m^3)**	**Theoretical Density (kg/m^3)**	**Air Content (%)**
		Empty Mould	**Mould + Concrete**					
C	1	0.78	8.74	0.00338	2358.52	2356.54	2400	1.81
	2	0.78	8.74	0.00338	2358.52			
	3	0.78	8.72	0.00338	2352.59			
C(D)	1	0.78	8.76	0.00338	2364.44	2364.44	2400	1.48
	2	0.78	8.78	0.00338	2370.37			
	3	0.78	8.74	0.00338	2358.52			
C(W)	1	0.78	8.66	0.00338	2334.81	2330.86	2400	2.88
	2	0.78	8.62	0.00338	2322.96			
	3	0.78	8.66	0.00338	2334.81			
SP0.1	1	0.78	8.82	0.00338	2382.22	2388.15	2400	0.49
	2	0.78	8.84	0.00338	2388.15			
	3	0.78	8.86	0.00338	2394.07			
SP0.2	1	0.78	8.88	0.00338	2400.00	2396.05	2400	0.16
	2	0.78	8.88	0.00338	2400.00			
	3	0.78	8.84	0.00338	2388.15			
SP0.3	1	0.78	8.74	0.00338	2358.52	2376.30	2400	0.99
	2	0.78	8.82	0.00338	2382.22			
	3	0.78	8.84	0.00338	2388.15			
SP0.4	1	0.78	8.84	0.00338	2388.15	2380.25	2400	0.82
	2	0.78	8.78	0.00338	2370.37			
	3	0.78	8.82	0.00338	2382.22			

Appendix H (Continued)

SP0.5	1	0.78	8.78	0.00338	2370.37	2368.40	2400	1.32
	2	0.78	8.72	0.00338	2352.59			
	3	0.78	8.82	0.00338	2382.22			
SP0.6	1	0.78	8.82	0.00338	2382.22	2356.54	2400	1.81
	2	0.78	8.74	0.00338	2358.52			
	3	0.78	8.64	0.00338	2328.89			
SP0.7	1	0.78	8.74	0.00338	2358.52	2360.49	2400	1.65
	2	0.78	8.8	0.00338	2376.30			
	3	0.78	8.7	0.00338	2376.30			

Appendix I: Hardened Density for 7 and 28 Days of Curing Age.

Specimen	Curing Period	Sample	Weight (kg)	Volume (m^3)	Density (kg/m^3)	Average Density (kg/m^3)
C	7-days	1	7.98	0.00333	2396.36	2402.02
		2	8	0.00332	2407.14	
		3	8.06	0.00335	2402.56	
	28days	1	7.98	0.00332	2402.79	2405.92
		2	8	0.00332	2408.76	
		3	8.04	0.00334	2406.22	
C(D)	7-days	1	8	0.00337	2375.48	2396.49
		2	8.04	0.00334	2409.66	
		3	7.98	0.00332	2404.33	
	28days	1	7.98	0.00335	2380.55	2401.55
		2	8.02	0.00332	2414.95	
		3	7.98	0.00331	2409.16	
C(W)	7-days	1	7.86	0.00336	2340.03	2338.31
		2	7.82	0.00335	2334.77	
		3	7.84	0.00335	2340.14	
	28days	1	7.84	0.00334	2344.95	2346.79
		2	7.82	0.00331	2359.69	
		3	7.82	0.00335	2335.73	
SP0.1	7-days	1	8.00	0.00333	2402.40	2386.87
		2	7.98	0.00335	2382.09	
		3	7.96	0.00335	2376.12	
	28days	1	7.98	0.00333	2396.40	2389.64
		2	7.98	0.00333	2396.40	
		3	7.96	0.00335	2376.12	
SP0.2	7-days	1	7.94	0.00338	2352.59	2392.13
		2	8.14	0.00338	2411.85	
		3	8.08	0.00335	2411.94	
	28days	1	7.92	0.00335	2364.18	

Appendix I (Continued)

		2	8.12	0.00335	2423.88	
		3	8.04	0.00335	2400.00	
SP0.3	7-days	1	8.06	0.00338	2388.15	2374.32
		2	8.06	0.00338	2388.15	
		3	7.92	0.00336	2346.67	
	28days	1	8.04	0.00335	2400.00	2378.99
		2	8.02	0.00337	2379.82	
		3	7.92	0.00336	2357.14	
SP0.4	7-days	1	8.04	0.00338	2382.22	2386.17
		2	8.02	0.00338	2376.30	
		3	8.04	0.00335	2400.00	
	28days	1	8.04	0.00335	2382.22	2388.1
		2	8.00	0.00335	2388.06	
		3	8.02	0.00335	2394.03	
SP0.5	7-days	1	8.04	0.00338	2378.70	2389.74
		2	8.08	0.00338	2390.53	
		3	8.04	0.00335	2400.00	
	28days	1	8.02	0.00338	2372.78	2392.92
		2	8.06	0.00335	2405.97	
		3	8.04	0.00335	2400.00	
SP0.6	7-days	1	7.96	0.00337	2362.02	2357.71
		2	7.96	0.00338	2355.03	
		3	7.94	0.00337	2356.08	
	28days	1	7.94	0.00336	2363.10	2363.1
		2	7.96	0.00337	2362.02	
		3	7.92	0.00335	2364.18	
SP0.7	7-days	1	7.88	0.00335	2352.24	2366.11
		2	7.90	0.00335	2358.21	
		3	7.88	0.00330	2387.88	
	28days	1	7.86	0.00333	2360.36	2371.54
		2	7.88	0.00333	2366.37	
		3	7.88	0.00330	2387.88	

Appendix J: Compressive Strength for 7 and 28 Days of Curing Age.

Specimen	**Compressive Strength (MPa)**							
	7 days				**28 days**			
	1	**2**	**3**	**Average**	**1**	**2**	**3**	**Average**
C	22.9	24.03	23.5	23.48	31.08	31.33	30.48	30.96
C(D)	18.38	17.31	16.22	17.3	24.57	22.33	23.66	23.52
C(W)	16.8	16.75	16.33	16.63	22.99	21.89	21.33	22.07
SP0.1	23.15	21.73	18.61	21.16	25.64	28.76	33.72	29.37
SP0.2	24.42	21.82	22.55	22.93	31.55	30.71	29.82	30.69
SP0.3	22.75	23.43	25.12	23.77	32.87	32.76	30.31	31.98
SP0.4	26.03	23.76	24.13	24.64	30.42	31.79	32.48	31.56
SP0.5	24.42	26.24	25.72	25.46	34.06	30.12	33.04	32.41
SP0.6	22.89	22.46	23.87	23.07	30.61	29.65	28.97	29.74
SP0.7	22.79	22.28	21.75	22.28	25.76	28.89	29.45	28.03