AN EXPERIMENTAL STUDY INVESTIGATING THE IMPACT OF DELAYED CASTING ON THE SLUMP BEHAVIOR AND COMPRESSIVE STRENGTH OF GRADE 30 CONCRETE AFTER RE-DOSING WITH HIGH-RANGE SUPERPLASTICIZER

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SOO HUI WEN

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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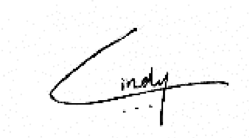
October 2024

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.

Signature : 

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"AN EXPERIMENTAL STUDY INVESTIGATING THE IMPACT OF DELAYED CASTING ON THE SLUMP BEHAVIOR AND COMPRESSIVE STRENGTH OF GRADE 30 CONCRETE AFTER RE-DOSING WITH HIGH-RANGE SUPERPLASTICIZER"** was prepared by **SOO HUI WEN** 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

Concrete is ideally placed immediately after mixing, but delays are common in the ready-mixed concrete industry due to factors like long transportation distances, traffic congestion, and placement delays. These delays often cause the concrete to stiffen by the time it arrives at the site, leading to a significant reduction in workability, which can make placement difficult and negatively impact the concrete's strength. To address this, superplasticizers can be used to restore the concrete's plasticity, or, as a common approach, extra water is sometimes added to the mixture before discharge. This study aims to examine the effects of casting delays (slump reduction from 100mm to 50mm) on the slump behaviour and compressive strength of grade 30 concrete. It also explores the effects of retempering with water and the impact of re-dosing with varying dosages of the high-range superplasticizer, MasterGlenium ACE 8538, in dosages from 0.05% to 0.30% at 0.05% intervals. Workability tests revealed that a 0.1% dosage of high-range superplasticizer was sufficient to restore the workability of the control mix, while a 0.15% dosage achieved the highest workability before segregation occurred. It was also found that although retempering with water can improve workability, it may significantly reduce compressive strength. In contrast, re-dosing with an appropriate amount of superplasticizer improves both workability and compressive strength, making it the more favorable retempering method. This study also identified the optimal dosage as 0.1% for regaining slump and 0.15% for achieving the best balance of workability and strength.

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LIST OF SYMBOLS / ABBREVIATIONS

A	air content, %
A_c	cross-sectional area of specimen, m^2
D	density of concrete, kg/m^3
F	maximum load at failure, N
f_c	compressive strength, MPa
m	mass of the specimen, kg
T	theoretical density of concrete, kg/m^3
V	volume of the specimen, m^3
V_c	volume of container, m^3
W_c	weight of container filled with concrete, kg
W_e	weight of empty container, g
W_f	weight of fully compacted concrete, g
W_p	weight of partially compacted concrete, g
ρ	hardened density of concrete, kg/m^3

Al	aluminium
Al_2O_3	alumina
ASTM	American Society for Testing and Materials
BS EN	British Standards European Norm
CaO	calcium oxide
Fe_2O_3	iron (III) oxide
FM	fineness modulus
K_2O	potassium oxide
MgO	magnesium oxide
Na_2O	sodium oxide
NC-C	normal concrete control mix
NC-D	normal concrete subjected to delayed casting
NC-W	normal concrete subjected to retempering with water
NC-0.05	normal concrete subjected to retempering with 0.05% superplasticizer
NC-0.1	normal concrete subjected to retempering with 0.1% superplasticizer

NC-0.15	normal concrete subjected to retempering with 0.15% superplasticizer
NC-0.2	normal concrete subjected to retempering with 0.2% superplasticizer
NC-0.25	normal concrete subjected to retempering with 0.25% superplasticizer
NC-0.3	normal concrete subjected to retempering with 0.3% superplasticizer
OPC	ordinary portland cement
PL	passing ability ratio
SiO_2	silicon dioxide
SO_3	sulphur trioxide
SP	superplasticizer
TPR	total percentage retained
W/C	water to cement ratio

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Concrete represents the primary and most widespread type of construction material, consisting of various ingredients such as fine and coarse aggregate, cement, and water (Alsadey and Omran, 2022). Assessing concrete properties at an early age is crucial for ensuring high construction quality, as these properties have a significant impact on the concrete's long-term performance. One crucial rheological property of fresh concrete, slump loss, plays a vital role in examining concrete's strength and durability. Slump loss refers to the decrease in concrete consistency over time, which is directly related to the reduction of free water caused by chemical and physical processes when mixing, primarily cement hydration and evaporation (Erdogdu, 2004).

The cement hydration and evaporation are directly influenced by the duration of various concrete operations, including mixing, delivery, placement, compaction, and finishing (Erdogdu, 2004). As the elapsed time increases, the depletion of free water in fresh concrete intensifies, leading to higher slump loss. Prolonged mixing in the truck mixer can also raise temperatures, accelerating cement hydration and evaporation of free water (Kirca, Turanli, and Erdogan, 2002). These conditions are common in ready-mixed concrete sector due to factors such as long transportation distances, traffic congestion, and delays in placement.

Due to slump loss, concrete quickly stiffens, leading to significant reductions in rheological properties like consistency, workability, and fluidity (Erdogdu, 2004). This makes it challenging to handle and manipulate during placement and compaction, resulting in decreased ultimate strength and reduced durability (Erdogdu, 2004). In the ready-mixed concrete sector, the primary challenge is to maintain concrete consistency at the desired level just before placement while ensuring the strength meets specified requirements. This can be achieved by incorporating a chemical admixture known as superplasticizers.

Superplasticizers, also referred to as high-range water reducers, are synthetic organic compounds used to decrease the amount of water needed for a desired workability of fresh concrete. (Eicha, 2020). This reduction significantly lowers the water to cement ratio, enhancing the workability and mechanical properties of concrete. Superplasticizers function by diminishing the interparticle forces among cement particles, ensuring their even dispersion in the concrete mix. By dispersing the cement particles, additional water becomes accessible for the mixing of concrete.

Superplasticizers enhance the properties of concrete in both its fresh and hardened states. In the fresh state, they reduce the tendency to bleed by reducing the water to cement ratio (Binns, 2003). If the water-cement ratio is maintained, a superplasticizer can extend the setting time of concrete by providing more water to lubricate the mix (Alsadey and Omran, 2022). In the hardened state, the use of superplasticizer increases compressive strength by improving compaction effectiveness, resulting in denser concrete (Alsadey and Omran, 2022). Additionally, the presence of superplasticizer reduces the risk of drying shrinkage and the rate of carbonation of the concrete (de Brito et al., 2016).

1.2 Importance of the Study

This study explores the effects of MasterGlenium ACE 8538 superplasticizer, a product of Master Builders Solutions Malaysia Sdn Bhd, on the slump retention and compressive strength of grade 30 concrete at various dosages. With this study, the optimum dosage for achieving the best workability and strength of concrete can be found. Additionally, the study will investigate the dosage effect on other fresh properties such as flowability, compactability, and density of the concrete. The optimal dosage of superplasticizer varies depending on the brand, type, and concrete mix proportions. Different superplasticizer also possesses distinct characteristics on the fresh properties of concrete. Therefore, this research is essential to gain a deeper understanding of this specific brand of high-range superplasticizers. Furthermore, the study will investigate the common practice of adding water before discharge to enhance concrete workability, analysing its impact on both the fresh and hardened properties of concrete.

1.3 Problem Statement

Unexpected delays in casting can lead to a significant loss of workability, rendering the concrete unmanageable. Concrete that has partially set or become overly stiff is often rejected on-site, resulting in wasted costs, as mixed concrete is an expensive material. Superplasticizers are used to restore the plasticity of concrete, making it workable again for placement and compaction. In addition to using superplasticizer, another common approach to address slump loss is by adding extra water to the concrete mixture prior to discharge. This restores the initial slump and maintains workability at sites. It is crucial to understand how the dosage of superplasticizers and the addition of water can impact the fresh properties of concrete, such as flowability, mobility, and compatibility, as these properties have a substantial impact on the quality of the hardened concrete. Studies have investigated the impact of superplasticizer dosage on the workability of concrete using different generations of superplasticizers. Research has explored the effects of 1st generation superplasticizers like Lignosulfonate (Sukh, Hooda, and Singh, 2023), 2nd generation superplasticizers such as Sulphonated Naphthalene Formaldehyde (SNF) Condensate (Ravindrarajah, 1985), and 3rd generation superplasticizers like Glenium C380 (Alsadey and Johari, 2016), Liboment – 163 (Alsadey, 2015), and other polycarboxylate ether-based superplasticizers. However, there is a lack of research regarding the impact of the high-range superplasticizer MasterGlenium ACE 8538 on concrete workability.

Moreover, it is important to observe the dosage effect of superplasticizers and the impact of water addition on the compressive strength of the concrete. Adding water typically increases the water-to-cement ratio, resulting in a significant strength reduction and potential failure to meet strength requirements. Additionally, it is crucial to determine the extent to which the addition of superplasticizers enhances the strength of concrete compared to concrete without superplasticizers. As previously noted, prior studies have focused on other types of superplasticizers. A study conducted by Erdogdu (2024) also investigated melamine-based superplasticizer, comparing the effects of retempering with superplasticizers and water on the compressive strength of concrete undergoing prolonged mixing. Similarly, there is a lack of studies on how the dosage of high-range superplasticizers, particularly MasterGlenium

ACE 8538, affects concrete's compressive strength. Therefore, further research in this area is essential.

Lastly, determining the optimal dosage of superplasticizer is a major challenge, as its effectiveness depends on the dosage and how evenly it is distributed in the mixture (Antoni, et al., 2017). Utilizing dosages below or above the optimal level may not yield the desired outcomes and could potentially have adverse effects on the concrete properties. On top of that, each brand of superplasticizer behaves uniquely and possesses distinct characteristics, necessitating specific dosage requirements to achieve well-mixed, uniform, and predictable fresh concrete. As a result, numerous trials are required before application, leading to wasted time and cost.

1.4 Aim and Objectives

The aim of this research is to investigate the impact of varying dosages of high-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:

1. To compare the fresh properties of untreated concrete, concrete treated with water addition, and concrete treated with high-range superplasticizer.
2. To compare the hardened properties of untreated concrete, concrete treated with water addition, and concrete treated with high-range superplasticizer.
3. To determine the optimal dosage of high-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 is centered on investigating the impact of MasterGlenium ACE 8538 superplasticizer on the properties of grade 30 concrete mixes. This research will be conducted while keeping the mix ratio, cement type, and properties of fine and coarse aggregates constant. Dosages ranging from 0.05% to 0.30% will be examined, with intervals of 0.05%. The study will assess both the fresh and hardened properties of the concrete and compare the results with concrete that has been retempered with water, as well as normal concrete that has not been retempered. Fresh property tests, including slump tests, compacting factor tests, density/air content tests, and vee-bee consistometer tests, will be conducted. Hardened tests, including compressive strength tests, will also be carried out. Cube specimens measuring 150mm×150mm×150mm will be cast for the experiments, requiring a total of 54 cubes for this investigation. The hardening and settling processes will require 24 hours to complete, and the concrete will be cured for 7 and 28 days for both trial and actual mixes.

1.6 Contribution of the Study

Delayed casting can lead to a significant loss of concrete workability and compressive strength. Superplasticizers become crucial in such scenarios as they can be added on-site to restore plasticity. This study aims to provide a more comprehensive understanding of high-range superplasticizers, an area where research is currently limited. It seeks to investigate the effects of different dosages of these superplasticizers on both the fresh and hardened properties of concrete. Additionally, the study aims to determine the optimal dosage necessary to achieve the best balance of workability and strength in concrete. This finding can serve as a valuable guide for future users of high-range superplasticizers, minimizing the need for trial and error, and consequently reducing costs and time. Moreover, the research aims to raise awareness in the construction industry about the implications of adding excess water to concrete, which can compromise its strength and hinder its ability to meet design strength requirements.

1.7 Outline of the Report

This report is organized into five chapters: Introduction, Literature Review, Methodology, Results and Discussion, and Conclusion and Recommendations. Chapter One provides a general introduction to the study, discussing its importance, problem statement, aim and objectives, scope and limitations, and contributions. Chapter Two presents a literature review of previous research related to the study, including discussions on raw materials such as Ordinary Portland Cement (OPC) and aggregate. In Chapter Three, a detailed methodology and work plan are outlined, covering the preparation of raw materials, procedures for conducting trial and actual mixes, and procedures for performing concrete tests. Next, Chapter Four presents the results and discussion, detailing the trial mix results and determining the optimal mix proportion for the actual mix. It also compares and discusses the effects of different superplasticizer dosages on the fresh and hardened properties of the concrete. Finally, Chapter Five concludes the study's findings in relation to the objectives and provides recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter offers a thorough review of the literature on superplasticizers and their effects on concrete properties. It examines the characteristics and mechanisms of three generations of superplasticizers, including natural polymers, synthetic linear polymers, and comb-shaped copolymers. The review also highlights previous research on how superplasticizers influence both the rheological properties and compressive strength of concrete. In addition, it discusses studies on the impact of delayed casting and water addition on the workability and compressive strength of concrete. The chapter also includes an introduction to the materials used, such as Ordinary Portland Cement (OPC) and aggregates.

2.2 Types of Superplasticizers

Superplasticizers are additives used to enhance the fluidity of concrete without increasing water content (Nkinamubanzi, Mantellato and Flatt, 2016). They find application in various scenarios. Firstly, they are employed when workability needs improvement without changing the water/cement ratio, which is critical for concrete durability and strength. This allows for the creation of self-levelling concrete that is pumpable and requires minimal compaction effort. Such fluidized concrete significantly reduces the likelihood of aggregate segregation or water separation. Secondly, superplasticizers are utilized when the water/cement ratio must be lowered without sacrificing workability, resulting in higher-strength concrete. This can yield concrete with strengths of up to 60 MPa under standard curing conditions and even exceeding 150 MPa with autoclaving (Singh, 2023). Lastly, superplasticizers can offset the initial strength reduction that occurs when mineral admixtures are used as cement replacements, even though they do not react as rapidly with water. (Nkinamubanzi, Mantellato and Flatt, 2016).

The application of superplasticizer in concrete construction offers environmental benefits. It reduces the cement content required to produce concrete, leading to lower carbon emissions from cement manufacturing sector. In addition, it decreases water consumption during concrete production, contributing to water conservation efforts. Moreover, superplasticizers allow for the reduction of concrete volume needed to achieve a specified weight-bearing capability, minimizing material usage and waste generation. By enhancing concrete durability, superplasticizers also contribute to extending the lifespan of concrete structures, which reduces the need for frequent repairs or replacements and ultimately decreases the environmental impact of concrete construction (Nkinamubanzi, Mantellato and Flatt, 2016).

Superplasticizers are classified into three generations, each distinguished by differences in molecular weight of the base component, chemical modifications, or the presence of other chemical substances, leading to the development of products with improved performance over different generations (Singh, 2023). These variations lead to diverse effects on cements. Detailed descriptions of the types of superplasticizers are outlined below.

2.2.1 1st generation SP: Natural Polymers

Natural polymers, also known as first-generation superplasticizers, are often considered as plasticizers or midrange water-reducing admixtures. They offer limited performance compared to synthetic polymers but are still popular in the concrete industry due to their cost-effectiveness. Lignosulphonate is a commonly used natural polymer and was the first dispersant employed as a water-reducing admixture in concrete. It is derived as a by-product of bisulphite pulping of wood, a process that separates pure cellulose fibres by dissolving hemicellulose and lignin (Gelardi, et al., 2016). The use of lignosulphonates in this capacity dates back to the 1930s (Flatt and Schober, 2012). They have a limited ability to reduce water content, typically around 10%, and are usually added at a dosage of 0.1%-0.3% by weight of cement. Lignosulphonates are mainly used in concrete mixes to improve the retention of workability, especially in ready-mix contexts. (Yuan, et al., 2021).

2.2.2 2nd generation SP: Synthetic linear polymers

Common examples of second-generation superplasticizers, which are synthetic linear polymers, include Sulphonated Naphthalene Formaldehyde (SNF)

Condensate, Sulphonated Melamine Formaldehyde (SMF) Condensates, and vinyl copolymers (Gelardi, et al., 2016). SNF, also known as polynaphthalene sulfonates (PNS), can reduce water content by up to 30% (Nkinamubanzi, Mantellato and Flatt, 2016). It was first used in the production of synthetic rubber and textile chemicals in 1930 before being utilized as a superplasticizer in concrete in the 1960s (Gelardi, et al., 2016). PNS superplasticizer is produced by sulfonating naphthalene with sulfuric acid or SO3, then treating it with sodium hydroxide and reacting it with formaldehyde (Aicha, 2020).

On the other hand, Sulphonated Melamine Formaldehyde (SMF) Condensates, also known as Polymelamine sulfonate (PMS), can decrease the water content in concrete by more than 20 to 30% (Nkinamubanzi, Mantellato and Flatt, 2016). PMSs have been employed in the concrete industry since the 1970s. It is derived from melamine before undergoing polymerization and reaction with sodium bisulfite. Initially, melamine is converted to trimethyl melamine and subsequently treated with formaldehyde. (Aicha, 2020). Compared to other type of superplasticizers, PNS and PMS superplasticizers are typically used in higher dosages (0.5%–1.0% by weight of cement) due to their lack of air entrainment properties (Singh, 2023).

Another common type of synthetic linear polymers includes vinyl copolymers, which are produced by radical copolymerization. They were first developed in the 1970s (Aicha, 2020). Unlike PNS- or PMS-based polymers, vinyl copolymers have a broader range of functional monomers, allowing for more diverse structural designs due to compatibility with a large number of monomers. The monomers may contain anionic functional groups such as sulphonate, carboxylate, or phosphonate, as well as bridging functions like ether, amide, or amine groups. (Gelardi, et al., 2016). This variety leads to a broad range of copolymers tailored for specific applications, each with expected performance characteristics. When compared to PNS or PMS superplasticizers, the dosage of vinyl copolymers can be reduced by up to half for achieving equivalent plasticity or water reduction (Aicha, 2020). Additionally, vinyl copolymers exhibit greater dispersing efficiency and extended slump duration, although they do tend to induce higher hydration retardation (Gelardi, et al., 2016).

2.2.3 3rd generation SP: Comb-shaped copolymers

Comb-shaped copolymers, also known as polycarboxylate ethers, esters, or simply polycarboxylates (PCEs), represent the third generation of superplasticizers (Yuan, et al., 2021). They have a unique comb-like structure that sets them apart from first and second-generation superplasticizers. While first-generation SPs are bulky and second-generation ones are linear ionic polymers, comb-shaped SPs feature a main chain with carboxylic groups and non-ionic polyether side chains attached. This structural design allows for a wide range of molecular structures, leading to SPs with diverse properties suitable for various applications. On top of that, these SPs can reduce water content by up to 40%, allowing for the use of extremely low water/cement ratios (0.20 or less) while maintaining good workability, which corresponds roughly to the water needed for the cement to hydrate. Developed in the 1980s, this generation of superplasticizers revolutionized the development and extensive application of self-compacting and ultra-high-strength concrete (Gelardi, et al., 2016).

There are two primary synthetic methods employed to produce PCEs. The first method involves the free radical copolymerization of a monomer containing carboxylic groups with a monomer featuring a side chain. This method is more common, simpler, and cost-effective. In contrast, the second approach involves the preformed backbone containing carboxylic groups undergoing esterification or amidation with monofunctional PEG. (Gelardi, et al., 2016). The effectiveness of polycarboxylates depends on several factors, such as the length and chemical composition of the backbone and side chains, the arrangement of the side chains along the backbone, the density of anionic charges, and the type of linkage between the backbone functionalities and side chains (Yuan, et al., 2021).

2.3 Mechanism of Superplasticizers

Superplasticizers function by adsorbing onto particles, with the aim to reduce or eliminate the attractive interparticle forces that contribute to yield stress. This dispersal action separates cement particles, releasing water trapped within agglomerations (Sidney, 2012). Consequently, the paste and concrete become less viscous, leading to increased fluidity, which enables more efficient mixing and reduces the overall water requirement. The attractive forces are typically attributed to van der Waals interactions but may also involve electrostatic forces (Flatt and Schober, 2012). Superplasticizers operate through two main mechanisms: electrostatic repulsion and steric repulsion (Yuan, et al., 2021). The degree of these effects depends on the type and molar weight of the superplasticizers. It is acknowledged that sulfonated superplasticizers (PNS and PMS) primarily exhibit electrostatic repulsion, while polycarboxylate-based superplasticizers are known for their steric repulsion effects (Aicha, 2020).

Electrostatic repulsion involves the adsorption of superplasticizer molecules onto cement particles, imparting a strong negative charge. This charge causes the particles to repel each other, separating them and improving the fluidity of the concrete mix by reducing electrostatic force. On the other hand, steric repulsion involves the inhibition of reactive sites by creating physical barriers between cement particles. One side of the polymer chain attaches to the cement surface, while the unattached side creates repulsion. This effect is enhanced by the grafted side chains of comb-shaped superplasticizers, which protrude and hinder neighbouring particles from coming into close contact, thereby preventing the effective action of van der Waals forces. Steric repulsion has been recognized as more effective than electrostatic repulsion, as it significantly influences slump retention and allows for a larger reduction in water content, even at lower dosages (Yuan, et al., 2021). The two mechanisms are illustrated in Figures 2.1 and 2.2.

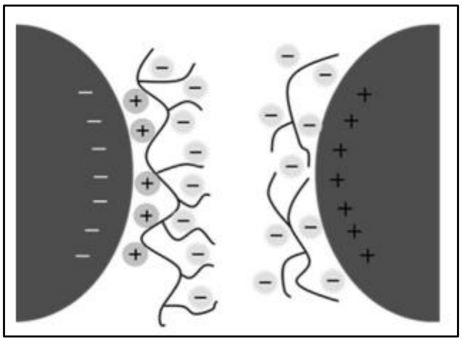


Figure 2.1: Illustration of Electrostatic Repulsion Mechanism (Yuan, et al., 2021).

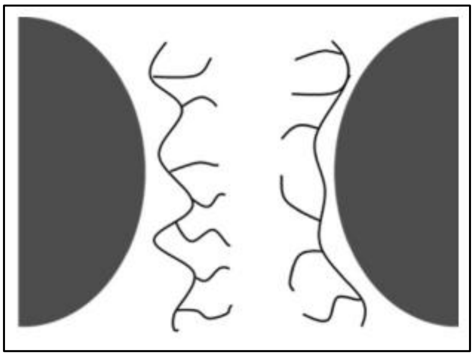


Figure 2.2: Illustration of Steric Repulsion Mechanism (Yuan, et al., 2021).

2.4 Effect of Superplasticizer on Rheological Properties of Concrete

This section investigates how superplasticizers affect the rheological properties of concrete. It examines how different dosages of superplasticizers impact the workability, mobility, and compactability of concrete, as determined by tests such as the slump test, vee-bee consistometer test, compacting factor test, and air content test.

2.4.1 Workability

Workability is determined by the internal work needed for complete compaction, with consistency, mobility, and compactability being key factors. Consistency reflects the fluidity of the concrete, while mobility refers to its ability to flow into formwork. Compactability relates to the ease of removing entrapped air, voids, and segregation from the mix. Ensuring adequate workability is crucial for achieving proper compaction and avoiding excessive porosity, which can compromise concrete quality (Rawarkar and Ambadkar, 2018). Several factors influence workability, including the ratio of water to cement, the type and amount of aggregates and cement used, the ratio of sand to aggregate, and the presence of additives (Rasheed, et al.,2018).

The addition of a superplasticizer can significantly enhance the flow of concrete, thereby improving workability. However, the effectiveness of the superplasticizer depends on its dosage. Initially, as the dosage increases, so does the flow enhancement, leading to increased workability. However, the dosage must exceed a minimum threshold, known as the critical dosage, to have a dispersing effect; below this dosage, no effect will be observed. Beyond the critical dosage, the flow continues to increase until it reaches a maximum level known as the saturation dosage. Further increases in dosage beyond this point have minimal impact on flow. Exceeding the upper-limit dosage can also result in detrimental effects such as segregation, bleeding, and delayed hardening (Flatt and Schober, 2012).

2.4.2 Slump

The slump test is a commonly employed technique for assessing workability, determining the ease with which concrete can be placed, transported, and compacted. Slump loss refers to the decrease in workability over time in fresh concrete (Flatt and Schober, 2012). The slump value serves as an indicator of concrete's flowability, with higher values indicating greater flowability. Specific slump values are used for various engineering applications. For example, a 0 mm slump is suitable for roller-compacted concrete, a slump of 160-220 mm is ideal for pumped concrete, and a slump exceeding 220 mm is typically used for self-compacting concrete (Yuan, et al., 2021). The slump profile may present in three different forms: true slump, where the concrete settles without significant deformation; shear slump, where the top portion shears off and shifts laterally; and collapse slump, where the concrete collapses entirely, often due to excessive moisture (Rawarkar and Ambadkar, 2018). It is important to note and evaluate this profile to assess the test's reliability.

Slump loss is sometimes viewed as a drawback of superplasticizers, which can limit their application. This is because the fluidizing effect of superplasticizers typically diminishes after 30–60 minutes, leading to a rapid decrease in workability afterwards (Singh, 2023). The extent of slump loss increases with higher superplasticizer dosages. For example, one study noted a rise in slump loss from 95mm to 170mm when the superplasticizer dosage was increased from 0.6% to 1.2% (Alsadey, 2012). Similarly, another study observed an increase in slump loss from 150mm to 190mm as the superplasticizer dosage increased from 0.4% to 1.2% (Alsadey and Johari, 2016). Figure 2.3 illustrates the slump loss over time for different dosages of superplasticizer used in the study. The control specimens, denoted as M and M1, had water-to-cement ratios of 0.56 and 0.66 respectively, without superplasticizers. The specimens labeled MS1 to MS5 represent concrete mixes with superplasticizer dosages of 0.4%, 0.6%, 0.8%, 1.0%, and 1.2% respectively.

As the dosage of superplasticizer increases, the slump loss also increases, and the rate of concrete setting slows down. A more detailed explanation of the setting time is provided in Section 2.4.3.

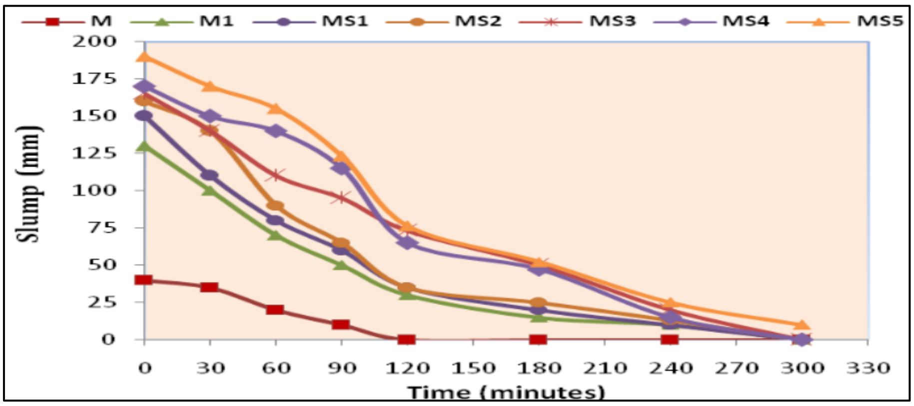


Figure 2.3: Effect of Superplasticizer Dosage on Slump Loss (Alsadey and Johari, 2016).

In a study conducted by Ravindrarajah (1985), the impact of incrementally adding superplasticizer to concrete at different intervals after mixing was investigated, highlighting the effect of retempering concrete subjected to delayed casting. The study reaffirmed that the slump value increases with higher dosages of superplasticizer. For instance, at 10 minutes elapsed time, quarter, half, and full dosage led to a slump increase of 30, 40, and 80 mm, respectively. The research also found that delaying the superplasticizer's addition reduced the increase in slump. Specifically, for the full dosage, the slump increase dropped from 80 mm to 20 mm when the superplasticizer was added 90 minutes after mixing instead of the initial 10 minutes. Likewise, for the half dosage, the slump gain decreased from 40 mm to 25 mm when the addition of superplasticizer was delayed from 10 minutes to 50 minutes. This suggests that the effectiveness of the superplasticizer in improving workability diminished with longer delay times.

2.4.3 Setting Time

The setting time of concrete refers to the period during which concrete hardens, transitioning from a plastic to a hardened state (Rasheed, et al.,2018). This process includes the initial set, when the concrete can no longer be easily handled or placed, and the final set, marking the beginning of hardening (Singh, 2023). The setting characteristics are influenced by factors such as the water/cement ratio, type and quantity of cement, cement fineness, temperature, and admixtures (Rasheed, et al.,2018).

Increasing the dosage of superplasticizer improves slump retention and extends slump life, keeping the concrete in a liquid state for a longer duration, thereby also slowing down the setting rate of the concrete. One study demonstrated this effect, with concrete setting times of 60 minutes without superplasticizer, 90 minutes with dosages of 0.6%, 0.8%, and 1.2%, and 120 minutes with dosages of 1.8% and 2.5% (Alsadey, 2015). The extent of the delay is contingent upon the type and dosage of admixture utilized. However, excessive dosages of admixtures can lead to substantial slump loss, resulting in inaccurate slump measurements and potentially causing issues such as segregation, bleeding, and extended initial setting times (Singh, 2023).

2.4.4 Vee Bee Consistometer Test

The vee-bee consistometer test indirectly assesses the workability of concrete and provides insight into its mobility and compatibility. In this test, compaction is achieved through vibration. The time required for the concrete to transform from a conical to a cylindrical shape is measured in seconds and recorded as the Vee Bee degree (Venkatraman and Ramasamy, 2020). A lower Vee Bee degree indicates better workability, as the concrete can be consolidated with minimal compacting effort. A study demonstrated this trend, showing a decrease in the Vee Bee degree from 5.09 seconds to 2.09 seconds as the superplasticizer dosage increased from 1% to 3%, highlighting the improved workability achieved with the higher superplasticizer dosage (Sukh, Hooda and Singh, 2023).

2.4.5 Compacting Factor Test

The compaction factor test examines how fresh concrete behaves under external forces and provides a more precise assessment of workability compared to the slump test. (Deepa, 2014). This test measures the level of compaction by allowing concrete to fall from a standardized height, measured by the compacting factor, which is the density ratio of partially compacted concrete weight to fully compacted concrete weight in the same container. A study conducted by Guruswamygoud, et al. (2021) observed that the compaction factor value increased with a higher percentage of superplasticizer. In the study, the compaction factor increased from 0.88 to 0.922 as the percentage of superplasticizer rose from 0% to 2%. Similarly, another study observed an increase from 0.89 to 0.92 in the compaction factor with a superplasticizer percentage increase from 0% to 1.5% (Isaac, 2019).

2.4.6 Air Content

According to Flatt and Schober (2012), superplasticizers can increase the air content in mortar or concrete mixes. While this can enhance workability to some degree, air contents exceeding 3% for non-air-entrained concrete should be avoided, as higher air contents can compromise compressive strength. To mitigate excessive air content, most superplasticizer formulations include a defoamer, particularly those based on lignosulfonates and PCEs. It is reported in a study by Fahim, Teemu, and Jouni (2019) that the increase in air content is more pronounced with PCE-based plasticizers compared to conventional ones. In the study, it was noted that raising the dosage of PCE-based superplasticizer from 0.4% to 1.6% led to an increase in air content from 0.42% to 0.57%, representing a 35.7% increase.

2.5 Effect of Superplasticizer on Compressive Strength of Concrete

Compressive strength is the maximum compressive stress that concrete is able to withstand. Superplasticizers enable a reduction in the water-cement ratio without affecting the slump, which helps achieve high-strength properties. Typically, reducing the water content by 25%–35% can lead to a 50%–75% increase in strength after 24 hours (Singh, 2023).

According to Alsadey (2015), the strength of concrete increases with the dosage of superplasticizers up to a saturation point. However, at very low dosages, the superplasticizer is unable to increase the compressive strength of concrete. As shown in Figure 2.4, the strength decreased from 37.68 MPa to 37.17 MPa when a superplasticizer dosage of only 0.6% was added to the concrete. Subsequently, with an increase in dosage to 0.8%, the compressive strength increased to 40.24 MPa. However, with a continued increase in dosage to 1.2%, 1.8%, and 2.5%, the compressive strength decreased to 36.75 MPa, 36.75 MPa, and 36.17 MPa respectively. This reduction in strength is attributed to bleeding and segregation due to overdosing, which affect the concrete's cohesiveness and uniformity.

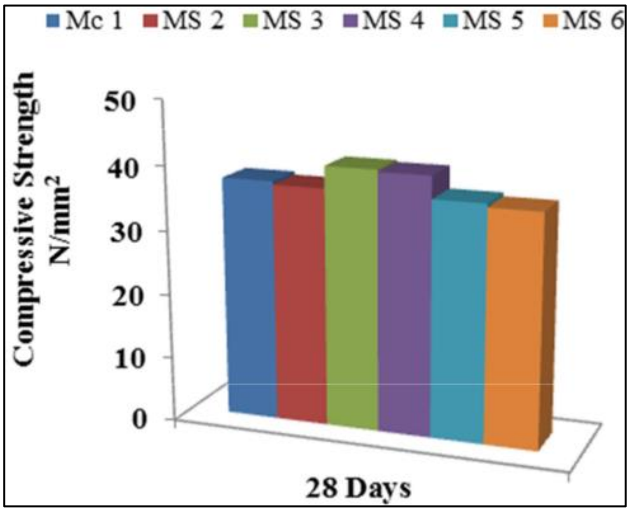


Figure 2.4: 28-Day Compressive Strength of Different Normal Concrete Mixes (Alsadey, 2015).

In another study conducted by Erdogdu (2004), it was observed that compressive strength increases gradually with elapsed mixing time. The concrete exhibited a strength increase of approximately 15% after 150 minutes of mixing. This increase is due to the decreased air content in the concrete during prolonged mixing, along with the effects of appropriate concrete placement and compaction. Additionally, the study investigated concrete that was retempered with water. It was noted that the concrete's strength reduced significantly within the first 90 minutes of mixing, after which it stabilized, leading to a decrease in strength of more than 40% by the end of 150 minutes. This indicates that adding significant amounts of water increases the water/cement content, leading to a substantial reduction in strength.

Additionally, the study also examined the strength of concrete subjected to retempering with superplasticizer. It was found that the strength of this concrete increased significantly within the first 90 minutes of mixing, but a moderate decrease was noted after that period. Compared to plain concrete, the retempered concrete exhibited a 10% higher strength at the end of the 90-minute mixing period and an 8% higher strength at the end of the 150-minute mixing period. The decline in strength after 90 minutes of mixing may be due to the modified rheological properties of fresh concrete as a result of prolonged mixing. Figure 2.5 presents the results of the study, comparing the effects of retempering with superplasticizers and water on the concrete's compressive strength subjected to prolonged mixing.

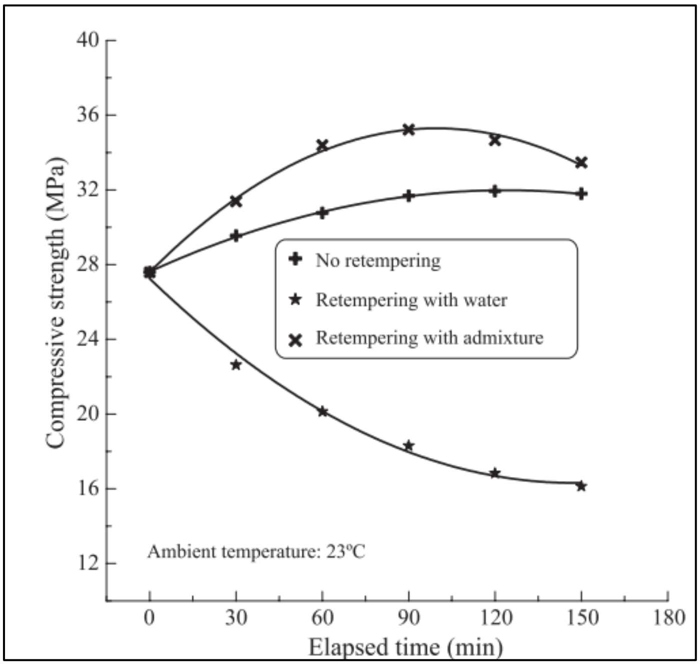


Figure 2.5: Retempering Effect on the Concrete's Compressive Strength Under Prolonged Mixing (Erdogdu, 2004).

2.6 Effect of Delayed Casting on Workability and Compressive Strength of Concrete

Fresh concrete should ideally be placed as soon as possible after mixing. However, unexpected delays can occur, which reduce the workability of the concrete, making it difficult to handle and manipulate during placement and compaction, ultimately leading to a reduction in concrete strength. Research by Mahzuz, Mehedi, and Nursat (2020) confirms that the workability of concrete decreases as delay time increases. This reduction in workability is due to the ongoing hydration process, which produces calcium silicate hydrate that fills the spaces between cement particles and aggregates, thereby reducing the concrete's fluidity (Alsadey, 2015).

A similar trend is observed when concrete is subjected to prolonged mixing. Erdogdu (2004) noted a rapid slump loss within the first 90 minutes of mixing, followed by a slower decrease. This is attributed to water absorption by the aggregate if the mix is not saturated, water loss through evaporation, and water removal due to initial chemical reactions (Pethkar et al., 2020). The higher water absorption rate of aggregates during extended mixing times also contributes to slump loss.

Mahzuz, Mehedi, and Nursat (2020) also found that the compressive strength of concrete samples gradually decreases as the delay time increases, with a significant drop occurring after one hour of delay, as shown in Figure 2.6. In this research, the rate of decrease in compressive strength is reported to be 8.16 MPa per hour of delay. A study by Pradeep and Abraham (2020) observed a similar trend, where the 28-day compressive strength of Grade 25 concrete decreased from 24.08 MPa to 20.48 MPa and 17.27 MPa as the delay time increased from 30 minutes to 1.5 hours and 2 hours, respectively.

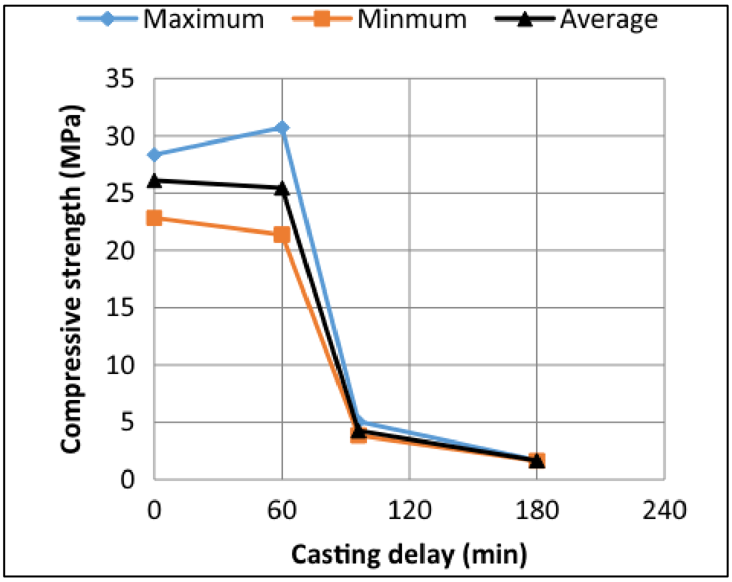


Figure 2.6: Compressive Strength of Concrete at Different Casting Delay (Mahzuz, Mehedi, and Nursat, 2020).

2.7 Effect of Water on Workability and Compressive Strength of Concrete

Retempering concrete with water improves its workability, resulting in a higher slump value. Yousri and Seleem (2018) demonstrated this effect, showing that adding water for retempering at 60 minutes after mixing increased the slump from 68mm to 105mm. Similarly, retempering at 120 minutes after mixing increased the slump from 40mm to 100mm. However, this practice generally reduces concrete compressive strength and increases susceptibility to cracking. The study revealed that, with the addition of water for retempering, increasing the water-cement ratio by 8.2% from 0.5 to 0.541, by 7.8% from 0.588 to 0.721, and by 5% from 0.65 to 0.682 led to reductions in 28-day compressive strength of 13%, 13%, and 6%, respectively.

Furthermore, another study by Erdogdu (2004), as mentioned in Section 2.5, found that concrete subjected to retempering with water experienced a strength reduction of over 40% compared to concrete that was not retempered. Figure 2.7 shows the relationship between strength loss and the amount of water added for retempering to restore the initial slump. The study concluded that the strength loss is directly proportional to the amount of retempering water used.

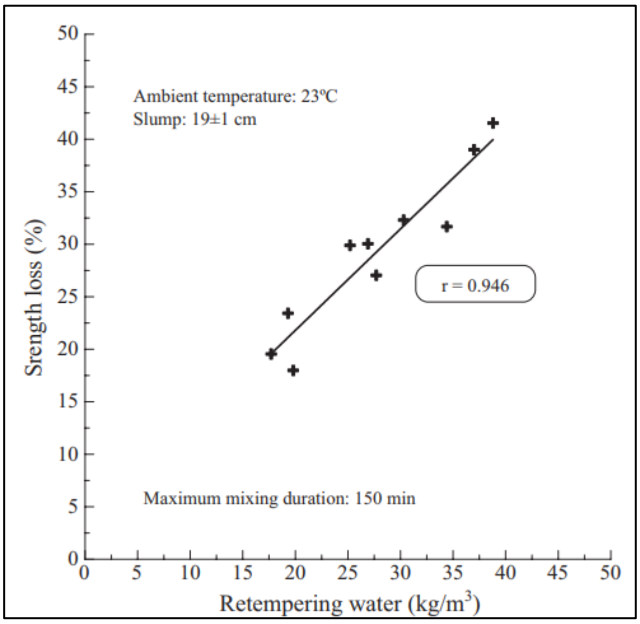


Figure 2.7: Relationship Between Retempering Water and Strength Loss of Concrete (Erdogdu, 2004).

The decrease in strength is associated with the addition of water that exceeds the design mixing water, leading to an increased water-cement ratio and a significant reduction in strength. Yaligar, Patil, and Prakash (2013) suggested three possible reasons for lower workability of concrete at delivery than specified: insufficient initial water batching, a greater evaporation or absorption rate than expected, and a greater hydration rate than anticipated. Adding water for retempering due to the first or second reason would not result in reduced strength, while adding additional water for the third reason would decrease strength. However, determining the specific reason for the lower workability of concrete at delivery is not feasible.

2.8 Materials

Concrete is composed of several components, including fine and coarse aggregate, cement, and water. This section provides a detailed discussion on ordinary portland cement and aggregate, two crucial elements in concrete composition.

2.8.1 Ordinary Portland Cement

Cement plays a vital role in concrete, providing both adhesive and cohesive properties. It sets, hardens, and bonds with other materials, effectively holding them together (Singh, 2020). When mixed with fine aggregate, cement produces mortar for masonry, and when combined with sand and gravel aggregates, it creates concrete. Portland Cement, a type of hydraulic cement, hardens through a reaction with water, resulting in a water-resistant product. It is manufactured by pulverizing clinkers primarily composed of hydraulic calcium silicates (Patnaikuni, Venugopal and Prabhakar, 2018). Table 2.1 illustrates the typical composition of Portland cement.

As per ASTM C150 (2007), Portland cement is classified into five main types, outlined in Table 2.2 along with their respective applications. Ordinary Portland Cement (OPC) falls under Type I and is typically chosen when specific cement properties are not needed. OPC is popular for its widespread availability and affordability.

Table 2.1: Typical Portland Cement Composition (Patnaikuni, Venugopal and Prabhakar, 2018).

Component	Percentage range by mass
CaO	60-69
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	2-4
MgO	1-5
SO_3	1-3
$Na_2O + K_2O$	0.3-1.5

Table 2.2: Application of Different Types of Portland Cement (ASTM C150, 2007).

Types	Application
I	General purpose
II	Moderate sulphate resistance or moderate heat of hydration is required
III	High early strength is required
IV	Low heat of hydration is required
V	High sulphate resistance is required

2.8.2 Aggregate

Aggregates are granular materials like sand, gravel, or stone that are mixed with a cementing medium to create mortar or concrete. Typically , aggregates make up 60% to 80% of the concrete volume. The characteristics of the aggregate substantially influence the concrete properties in its fresh and hardened states. These properties include workability, finish ability, segregation, bleeding, and pumpability of fresh concrete, along with the strength, durability, creep, density, permeability, and shrinkage of hardened concrete (Yuan, et al., 2021).

Aggregates can be categorized by their density into lightweight, normal weight, and heavyweight aggregates. As defined by ASTM C125 (2007), heavyweight aggregates have a relative density greater than 3.3, while lightweight aggregates have a bulk density lower than 1120 kg/m3. Normal weight aggregates fall in between these two extremes. The choice of aggregate type depends on the desired density of the concrete being produced. Additionally, aggregates can be classified by size into fine aggregate and coarse aggregate. Coarse aggregate is defined by ASTM C125 (2007) as the segment of aggregate retained on the 4.75-mm (No. 4) sieve, while fine aggregate is the segment of aggregate that passes through the 4.75-mm (No. 4) sieve and is retained on the 75-µm (No. 200) sieve.

Moreover, aggregates can be classified based on their origin into natural aggregates and manufactured aggregates. Natural aggregates result from the weathering and erosion of rocks, which are then deposited in rivers, lakes, or seabed. These aggregates typically have a rounded shape due to prolonged agitation in water. While this rounded shape makes them harder, their smooth surface can decrease the bond strength with the cement paste and, consequently, the strength of concrete. Manufactured aggregates, on the other hand, are produced by crushing parent rocks using machines. They typically exhibit a rough surface texture and angular shape, often appearing cubical or elongated. However, they may vary in size distribution, and their high content of crushed powder can influence the water requirements and concrete's workability. (Yuan, et al., 2021).

2.9 Summary

The addition of superplasticizers to concrete improves its fluidity without increasing water content. Previous research conducted by numerous scholars has demonstrated that superplasticizers can enhance both the workability and compressive strength of concrete. These improvements were evident in the test results for fresh and hardened concrete properties. However, it is crucial to determine the optimal dosage, as excessive amounts can lead to detrimental effects such as segregation and bleeding, while insufficient amounts may have minimal impact on the properties. Additionally, different types of superplasticizers operate through varying mechanisms and exert distinct effects on concrete properties. The superplasticizer chosen for this study is a third generation polycarboxylate ether (PCE) superplasticizer, for which a thorough literature review has been conducted. As the latest generation of superplasticizers, it is expected to exhibit excellent slump retention properties in concrete. Furthermore, studies also suggest that retempering concrete with water improves its workability but significantly reduces its compressive strength, a topic we will investigate further in our experiments.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter outlines the raw materials required for the research, the procedure for preparing the testing specimens, and the laboratory testing conducted to investigate the objectives of this study. The experiment was divided into two stages: the trial mix and the actual mix. The objective of the trial mix study was to determine the optimum water-to-cement (w/c) ratio, the achievable slump value of the mix, and the required concrete cube strength of at least 30MPa at 28 days. For the actual mix, the aim of this stage was to collect test data on the slump behavior and compressive strength after re-dosing with superplasticizer. Additionally, various fresh concrete tests were conducted during this stage of the experiment, including the vee-bee consistometer test, compacting factor test, and density test. The overall workflow process is illustrated in the flow chart in Figure 3.1.

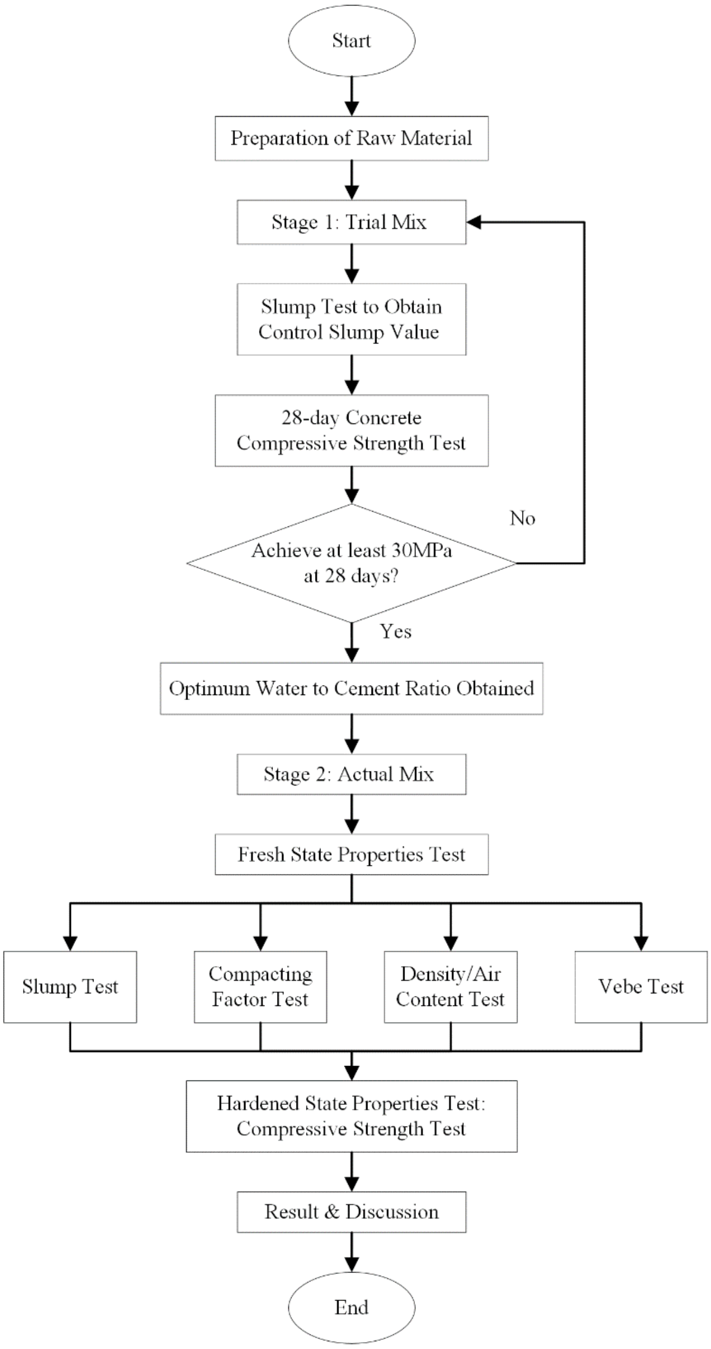


Figure 3.1: Flow Chart of the Workflow in the Experimental Study.

3.2 Raw Materials

This section covers the procedures and steps involved in preparing the necessary raw materials for the experimental tests, which include Ordinary Portland Cement (OPC), coarse aggregates, fine aggregates, water, and superplasticizer.

3.2.1 Ordinary Portland Cement (OPC)

For this study, Type I Ordinary Portland Cement (OPC) from YTL Cement Bhd was used, as shown in Figure 3.2. Marketed under the brand name Orang Kuat, this high-strength Portland cement conforms to the CEM I 52.5N standard. Orang Kuat cement is also certified according to Malaysia's MS EN 197-1:2014 standard. To eliminate lumps, the cement was first sieved through a 600μm sieve, as illustrated in Figure 3.3. It was then stored in airtight buckets to maintain a clean, moisture-free environment.

Figure 3.2: Cement Orang Kuat, CEM I 52.5N OPC.

Figure 3.3: Sieving of Cement.

3.2.2 Fine Aggregate

Fine aggregate, commonly referred to as sand, plays a crucial role in concrete production. For this study, local suppliers provided the fine aggregates, which were prepared according to the ASTM C33 Standard. As per ASTM C33 (2023), fine aggregates should fall within a size range smaller than 9.5mm. To ensure at least 95% of the aggregates passed through a 4.75mm sieve and were retained on a 150µm sieve, both 4.75mm and 150µm sieves were used. The aggregates that passed through the 4.75mm sieve and were retained on the 150µm sieve were collected in a bucket and stored in a clean container, as shown in Figure 3.4.

Figure 3.4: Fine Aggregate.

3.2.3 Coarse Aggregate

Coarse aggregate is another crucial component in concrete production. For this study, local suppliers provided the coarse aggregates, which were prepared according to the ASTM C33 Standard. The aggregates were sieved using 25mm and 4.75mm sieves. Aggregates that passed through the 25mm sieve and were retained on the 4.75mm sieve were collected in a bucket and stored in a clean container, as shown in Figure 3.5.

Figure 3.5: Coarse Aggregate.

3.2.4 Water

Water was an essential component in both the mixing and curing of concrete for this study. Municipal tap water, specifically laboratory tap water, was used. The water had to adhere to the ASTM C1602 standard to avoid compromising the concrete's strength or setting time. To meet this standard, the water was checked for impurities or sediments that could alter its density and solids content. Additionally, the water was kept at a constant room temperature of 27°C as shown in Figure 3.6. The required water quantity was calculated initially. Subsequently, after preparing all other materials, a clean bucket was designated to hold the water drawn from the laboratory tap. Water was only drawn when required to prevent it from being prepared too early, which could result in contamination by dust or other impurities during the preparation of other materials.

Figure 3.6: Mixing Water.

3.2.5 Superplasticizer

The superplasticizer utilized in this research was MasterGlenium ACE 8538, supplied by Master Builders Solutions Malaysia Sdn Bhd, as shown in Figure 3.7. This new generation of polycarboxylic ether (PCE) superplasticizer utilizes a unique polymer with long lateral chains of polycarboxylate ether. Its high water reduction, early strength development, and slump retention make it a favorable admixture for the ready-mix and precast concrete sector.

The superplasticizer was stored in its original container at room temperature. During the re-dosing stage, the superplasticizer was removed from its container, and the necessary volume was measured using a measuring cylinder. The required amount of superplasticizer for each mix was calculated in advance.

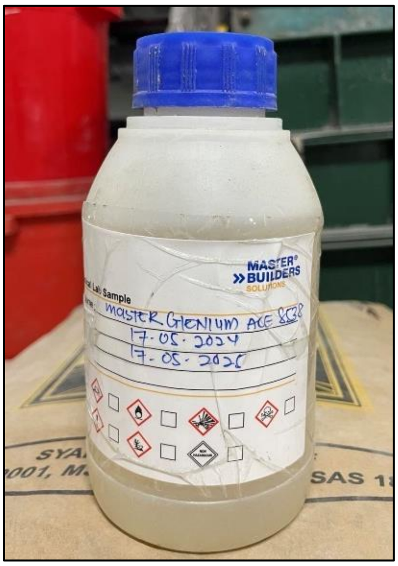


Figure 3.7: MasterGlenium ACE 8538 Superplasticizer.

3.3 Trial Mix

Prior to casting the actual mix specimens for the study, it was crucial to carry out trial mix to determine the optimal water-to-cement (w/c) ratio and mix proportion that would achieve a 28-day compressive strength of 30 MPa and exhibit a good slump value. 10 trial mixes were performed with variations in aggregate content, cement content, and w/c ratio. Slump tests were conducted after mixing each trial to record the slump value. Compression tests were also carried out on the concrete samples after 7 and 28 days of curing to evaluate the compressive strength of each mix proportion. The results of the slump tests and compressive strength tests were recorded and tabulated. A graph was generated to identify the mix proportion with the highest compressive strength. From the graph, the optimum mix proportion was determined for use in the actual mix stage.

3.4 Mix Procedure

The concrete mixing process was performed using a concrete mixer, following the ASTM C192/192M guidelines. First, the required amounts of Ordinary

Portland Cement (OPC), fine and coarse aggregate, and water were measured using a weighing machine and placed into buckets, as shown in Figure 3.8. The dry materials, including cement, fine aggregate, and coarse aggregate, were then added to the mixer and thoroughly mixed to ensure uniformity. Water was consistently added to achieve the desired water-to-cement (w/c) ratio, and the mixing process continued until the mix was uniformly blended. The concrete was then set aside, allowing the slump value to decrease. Slump tests were conducted regularly until the mix achieved a 50mm slump value, at which point water addition or superplasticizer re-dosing was implemented. The concrete was then remixed to ensure thorough mixing of the superplasticizer or water. Afterward, fresh concrete tests were conducted and results were recorded.

Figure 3.8: Weighted Materials Placed in Buckets.

Next, the fresh concrete mix was transferred to 150mm×150mm×150mm cube moulds in 3 layers. Each layer was consolidated by 25 strokes with the standard 5/8” diameter tamping rod. The cube moulds were oiled in advance as shown in Figure 3.9. After 24 hours, the cubes were demolded and placed in water for curing. Compressive strength tests were performed on the cubes after 7 and 28 days of curing, and the results were recorded. The entire process was repeated to create concrete mixes with varying dosages of superplasticizer.

Figure 3.9: Oiling of Cube Moulds.

3.5 Sieve Analysis

The sieve analysis was conducted for both fine and coarse aggregates in accordance with ASTM C33/33M to determine the aggregate gradation by analyzing the distribution of particle sizes. For the sieve analysis of fine aggregate, a shaker was prepared with a stack of test sieves arranged from the largest aperture size (9.5 mm) at the top to the smallest (150 µm) at the bottom, as shown in Figure 3.10. A 1000-gram sample of oven-dried sand was poured onto the top sieve, and a sieve pan cover was placed over the stack to prevent fine sand particles from dispersing into the air. The sieves were securely attached to the shaker machine and operated for 15 minutes to ensure thorough shaking without excessive agitation that could degrade the sand. The weight of material retained on each sieve was then determined and recorded.

Figure 3.10: Set Up of Sieve Analysis Test for Fine Aggregate.

The same testing procedure was repeated with a 1000-gram sample of oven-dried coarse aggregate. The test sieves were arranged from the largest aperture size (25 mm) at the top to the smallest (4.75 mm) at the bottom, as shown in Figure 3.11. Similarly, the weight of material retained on each sieve was determined and recorded. Finally, the fineness moduli of the aggregates were calculated using Equation 3.1, and grading curves were plotted.

Figure 3.11: Set Up of Sieve Analysis Test for Coarse Aggregate.

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

where

FM = fineness modulus

Σ TPR = total percentage retained

3.6 Curing

Curing is vital for enhancing the strength of freshly cast concrete. After one day of casting, the curing process commenced for all concrete specimens. Initially, the specimens were demolded and clearly labeled based on the superplasticizer dosage. According to ASTM C31/C31M (2022), water had to be maintained on the surfaces of the concrete samples throughout the curing process. As depicted in Figure 3.12, the cubic specimens were cured in a water tank with a heavy cover. The temperature of the curing water was maintained between 16°C and 27°C, in accordance with ASTM C31.

Figure 3.12: Water Curing for the Concrete Specimens.

3.7 Concrete Tests

The following sections describe the procedures for the concrete tests to be conducted in this study, which include slump test, vee-bee consistometer test, compacting factor test, fresh density test, compressive strength test, and hardened density test.

3.7.1 Slump Test

The slump test was conducted following the guidelines outlined in ASTM C143/C143M (2003). This procedure involved using a tamping rod measuring 16mm in diameter and 600mm in length, along with a metal truncated cone with a height of 300mm, and has a diameter of 100mm at the top and 200mm at the bottom. To begin, the mould was dampened and positioned on a flat surface. The mould was held in place during filling by standing on the two-foot pieces. Filling the mould was done in three layers, each roughly one third of the mould's volume. After each layer, the concrete was tamped using tamping rod for 25 times, evenly distributed over the layer's cross-section. Additional concrete was placed to ensure an excess on the mould's top due to the settling of the concrete during the tamping process. Following the tamping of the top layer, excess concrete was removed from the surface as shown in Figure 3.13. The mould was then lifted in a vertical direction to a distance of 300mm, without any lateral or torsional movement, to remove it. The test, from filling to removing the mould, was completed within 2.5 minutes as per ASTM C143/C143M recommendations. Finally, the slump cone was placed beside the slumped concrete, and a steel rod was positioned horizontally across the cone, extending over the slumped concrete. The vertical measurement from the base of the steel rod to the center of the specimen was measured, providing the slump value of the concrete.

Figure 3.13: Slump Test.

3.7.2 Vee-Bee Consistometer test

The vee-bee consistometer test was performed in accordance with BS EN 12350-3:2009 using a vee-bee consistometer, which comprises a vibrator table, a cylindrical mould, a metal cone, and a tamping rod. The test comprised two parts, the first of which replicated the conventional slump test. During this initial phase, the slump cone was positioned inside a cylinder container within the consistometer. The cone was then filled with concrete in four layers, each layer being one fourth the height of the cone. After pouring each layer, the concrete was tamped 25 times with the tamping rod and excess concrete was striked off from the top layer. In the second part, the electrical vibrator was activated, and the stopwatch was started simultaneously. The vibration continued until the concrete reshaped from a conical to a cylindrical form, and the concrete surface became horizontal, as shown in Figure 3.14. The elapsed time, rounded to the nearest second, represented the vee-bee consistency time.

Figure 3.14: Vee-Bee Consistometer Test

3.7.3 Compacting Factor Test

The compacting factor test was conducted in accordance with BS 1881: Part 103 (1983). The test utilized a compacting factor apparatus comprising two conical hoppers positioned above a cylinder, along with a scoop, tamping rod, and weighing scale. To prepare for the test, the inner surfaces of the hoppers and cylinder were wiped clean to ensure they were smooth and free from excess moisture. A concrete sample was carefully added to the upper hopper using a scoop until it reached the rim of the hopper. The trapdoor at the base of the upper hopper was opened to let the concrete sample fall into the lower hopper. After the concrete settled, the trapdoor of the lower hopper was opened to allow the concrete to fall into the cylinder underneath. Any excess concrete above the cylinder was striked off, and the outer surface of the cylinder was cleaned. The cylinder containing the concrete was then weighed to the nearest 10 g and recorded as the weight of partially compacted concrete. Next, the cylinder was emptied and replenished with the same concrete mix in 6 layers, each roughly equal in depth. Each layer was compacted with a tamping rod to achieve full compaction. After compacting the top layer, the top surface of the cylinder was smoothed, and the outer surface of the cylinder was cleaned. The cylinder containing the concrete was then weighed to the nearest 10 g and recorded as the weight of fully compacted concrete. Finally, the empty cylinder's weight was measured, and the compacting factor was determined using Equation 3.2. Figure 3.15 illustrates the apparatus of the compacting factor test.

$$Compacting\ Factor = \frac{W_p - W_e}{W_f - W_e} \tag{3.2}$$

where

W_p = partially compacted concrete weight, g

W_f = fully compacted concrete weight, g

W_e = empty cylinder weight, g

Figure 3.15: Compacting Factor Test.

3.7.4 Fresh density and Air Content Test

The fresh density and air content test conformed to the ASTM C 138/C 138M (2008) standard. The materials required to perform the test were a container, a weighing scale, and a tamping rod. The concrete was poured into the container and filled in three layers of roughly equal volume, with each layer being tamped 25 times using the tamping rod. Subsequently, the container was tapped to fill any voids remaining from the tamping rod and to remove any air bubbles that might have been captured. A small amount of concrete was added to correct any deficiency, and excess concrete was struck off from the surface. The outside of the container was wiped clean and weighed. Finally, the weight of the empty container was measured, and the fresh density of the concrete was determined using Equation 3.3.

$$D = \frac{W_c - W_e}{V_c} \quad (3.3)$$

where

D = fresh density, kg/m^3

W_c = weight of container filled with concrete, kg

W_e = weight of empty container, kg

V_c = volume of container, m^3

Subsequently, the air content of the concrete was determined using Equation 3.4.

$$A = \frac{T - D}{T} \times 100 \quad (3.4)$$

where

A = air content, %

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

D = density of concrete, kg/m^3

3.7.5 Compressive Strength Test

The compression test was carried out in accordance with BS EN 12390-3 (2019) using a compression testing machine. After the specified curing period, the cubic specimens were removed from the water tank and oven dried to eliminate excess water on their surfaces. To ensure accuracy, both the machine's bearing surface and the surfaces of the cubic specimens were cleaned thoroughly to remove any loose debris or foreign material. When positioning, the center of each cubic specimen was aligned with the base plate of the machine, and the specimens were oriented to ensure that the applied load will be perpendicular to the direction in which they were cast. Finally, a steadily increasing axial load was applied to the concrete specimens at a constant rate until failure occurred. The maximum load that the specimens could sustain was recorded, and the compressive strength of the specimens was determined using Equation 3.5. Figure 3.16 illustrates the equipment and setup of the compressive strength test.

$$f_c = \frac{F}{A_c} \tag{3.5}$$

where

f_c = compressive strength, MPa

F = maximum load at failure, N

A_c = specimen's cross-sectional area at which compressive force acts, m^2

Figure 3.16: Compressive Strength Test.

3.7.6 Hardened Density Test

After the designated curing period, the concrete specimens were removed from the water tank, and their surfaces were wiped with a cloth to remove excess moisture, achieving saturated mass as per ASTM C642. The weights of the specimens were measured using a weighing machine, while their dimensions were measured three times to obtain an average value, as shown in Figures 3.17 and 3.18, respectively. The hardened density of the concrete was then calculated using Equation 3.6.

$$\rho = \frac{m}{V} \tag{3.6}$$

where

ρ = hardened density, kg/m^3

m = mass of the specimen, kg

V =volume of the specimen, m^3

Figure 3.17: Weighing of Concrete using Digital Scale.

Figure 3.18: Measuring of Dimensions using Vernier Calliper.

3.8 Summary

In this chapter, the complete process of the study, from the preparation of the raw materials and mixing procedures to the testing methods, was discussed. The materials needed included Ordinary Portland Cement (OPC), coarse aggregates, fine aggregates, water, and superplasticizer. 10 trial mixes were conducted with variations in aggregate content, cement content, and water-to-cement (w/c) ratio. The optimum w/c ratio determined from these trials was then adopted for casting the actual mix. A total of 54 concrete cubic specimens were prepared, including the control, mixes retempered with superplasticizer dosages ranging from 0.05% to 0.3% by weight of cement, and mixes retempered with water. Fresh property tests, including slump tests, vee-bee consistometer tests, compacting factor tests, and density/air content tests, were carried out. Tests of hardened properties, including compressive strength and hardened density tests, were also conducted. All the mixing and testing procedures in this study followed BS and ASTM standards.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results of the sieve analysis were presented and discussed. The mix proportions, along with the results of the slump test and compressive strength test of the trial mixes, were analyzed to determine the optimum mix proportion for the actual mix. This optimal mix was then subjected to delayed casting, water addition, and various dosages of superplasticizer. The results of the concrete tests, including the slump test, vee-bee consistometer test, compacting factor test, density test, and compressive strength test, were subsequently presented and discussed.

4.2 Sieve Analysis

Sieve analysis was performed for both fine and coarse aggregates. After completing the sieve analysis, the weight of material retained on each sieve was determined and recorded. Subsequently, the percentage of aggregate retained and the cumulative proportion of course and finer particle grains were calculated and tabulated in Appendix A-1 and Appendix A-2, respectively. The fineness modulus of both aggregates were calculated by dividing the total cumulative percentage of aggregate retained by 100, as presented in Table 4.1. The grading curves for fine and coarse aggregates, plotted on a logarithmic scale, are presented in Figures 4.1 and 4.2, respectively.

Table 4.1: Fineness Modulus of Fine and Coarse Aggregate.

Material	Σ TPR (%)	Fineness Modulus
Fine Aggregate	233.94	2.34
Coarse Aggregate	677.78	6.78

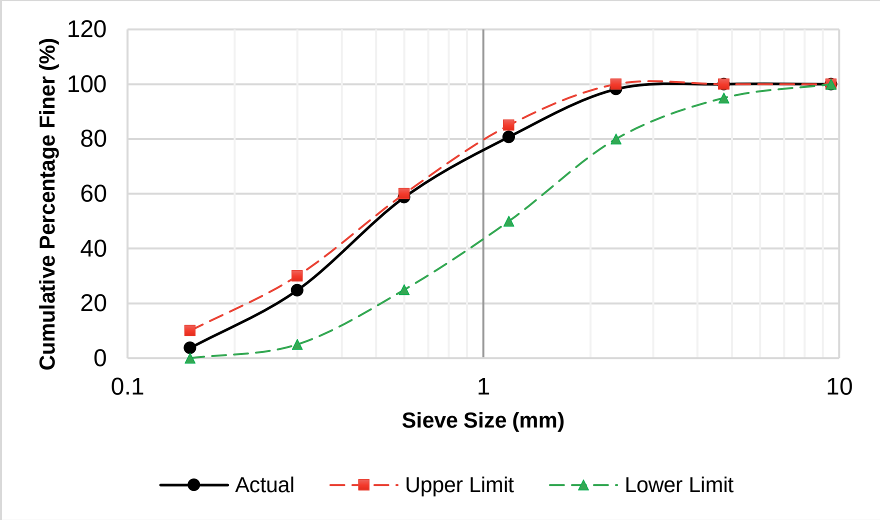


Figure 4.1: Grading Curve for Fine Aggregate.

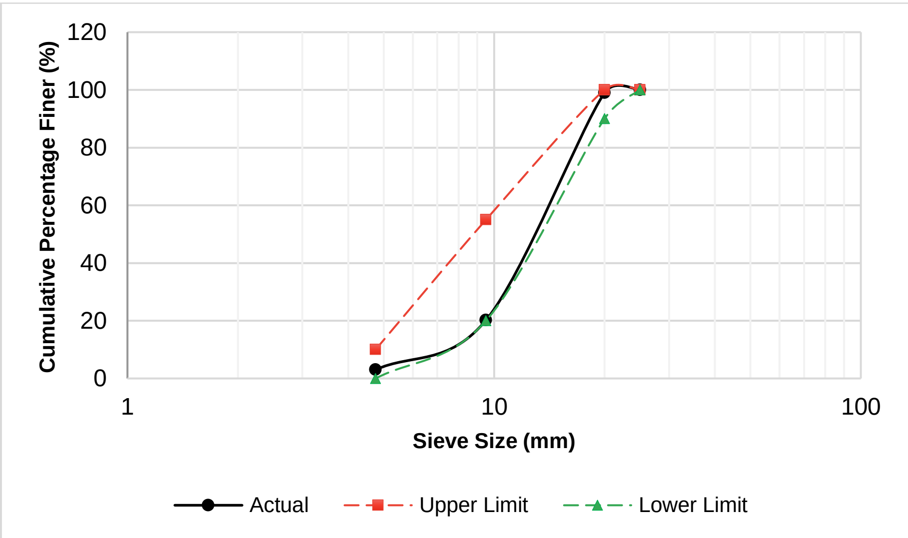


Figure 4.2: Grading Curve for Coarse Aggregate.

The grading curves of fine and coarse aggregates shown in Figures 4.1 and 4.2, respectively, are compared with the lower and upper limits of grading requirements according to the ASTM C33 standard. It is observed that both fine and coarse aggregates fall within the required range. The plotted grading curves also indicate that the aggregates are well-graded, meaning they have a good size distribution across a wide range with no intermediate sizes lacking. In addition, as shown in Table 4.1, the fineness modulus of the fine aggregate is calculated to be 2.34, indicating that the average particle size of the fine aggregate sample falls between the 2nd and 3rd sieves, or between 0.3mm and 0.6mm. This value is within the ASTM C33 standard requirement range of 2.3 to 3.1 for fine aggregates. On the other hand, the fineness modulus of the coarse aggregate is calculated to be 6.78, meaning the average particle size of the coarse aggregate sample falls between the 6th and 7th sieves, or between 4.75mm and 10mm. Overall, both the fine and coarse aggregates satisfy the ASTM C33 requirements and are suitable for use in concrete production.

4.3 Trial Mix

A series of trial mixes were conducted to determine the optimal water-to-cement (w/c) ratio and mix proportions needed to achieve a 28-day compressive strength of 30 MPa while maintaining a good slump value. 10 different trial mixes were prepared, varying the aggregate content, cement content, and w/c ratio from 0.5 to 0.7, as detailed in Table 4.2. The mixes are designated as M1, M2, and so forth, corresponding to Mix 1, Mix 2, up to Mix 10 (M10). The mix proportions for M1 to M7 conform to the Building Research Establishment (BRE) design guidelines, whereas M8 to M10 follow ASTM standards. Slump tests were performed after mixing each trial to measure the slump value. Additionally, compression tests were carried out on the concrete samples after 7 and 28 days of curing to assess their compressive strength. The results of these tests are tabulated and discussed in the following subsections.

Table 4.2: Mix Proportions of Trial Mixes.

Trial Mixes	Unit Weight (kg/m^3)					
	W/C Ratio	Cement	Water	Fine Aggregate	Coarse Aggregate	
					10mm	20mm
M1	0.5	350	175	693.75	393.75	787.50
M2	0.6	350	210	680.80	386.40	772.80
M3	0.7	350	245	667.85	379.05	758.1
M4	0.7	350	245	451.25	451.25	902.50
M5	0.65	350	227.5	455.63	455.63	911.25
M6	0.66	350	231	691.22	375.93	751.85
M7	0.7	321	224.7	556.29	432.67	865.34
M8	0.65	315	204	602	1279	
M9	0.63	340	215	789	1056	
M10	0.63	340	215	650	1195	

4.3.1 Slump Test

Slump cone tests were performed to assess the workability of fresh concrete for each trial mix. The tests were performed three times, and the results are provided in Appendix A-3. Figure 4.3 displays the average results for the different mixes. It is notable that only Mix 8 and Mix 10 achieved the target slump range of 100 ± 20mm, with average slump values of 117 mm and 102 mm, respectively. The lower slump value may be due to a low w/c ratio and excessive fine aggregate content. Fine aggregates, due to their larger surface area, require more water for surface wetting, which increases overall water demand. As a result, less water is available to lubricate the mix, leading to reduced workability.

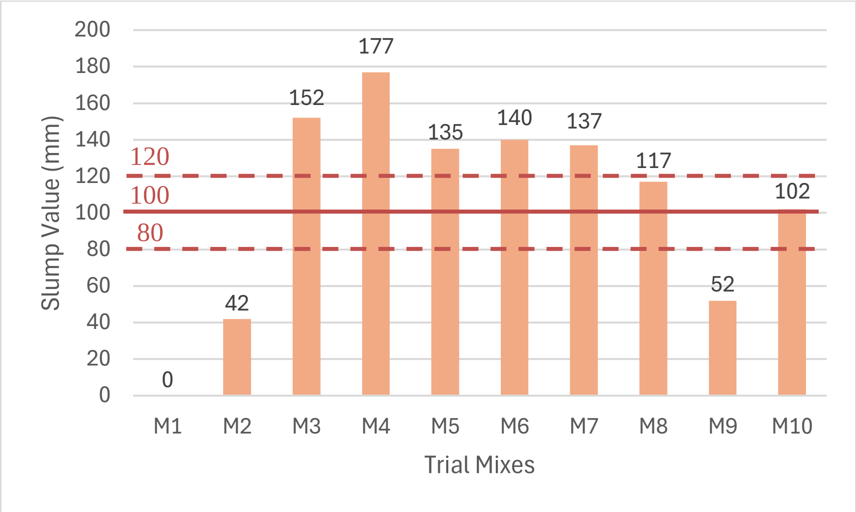


Figure 4.3: Slump Value of Trial Mixes.

4.3.2 Compressive Strength Test

Compressive strength tests were conducted on the concrete samples after 7 and 28 days of curing to evaluate their strength. 3 cube specimens were tested for each curing period, and the results are provided in Appendix A-4. The average compressive strength for the 7-day and 28-day tests of each mix is shown in Figure 4.4. Notably, only Mixes 3, 8, and 10 achieved the 28-day compressive strength of 30 MPa. However, only Mixes 8 and 10 met the target slump range of 100 ± 20mm. Mix 10 was selected for the actual mix due to its highest compressive strength of 31.90 MPa.

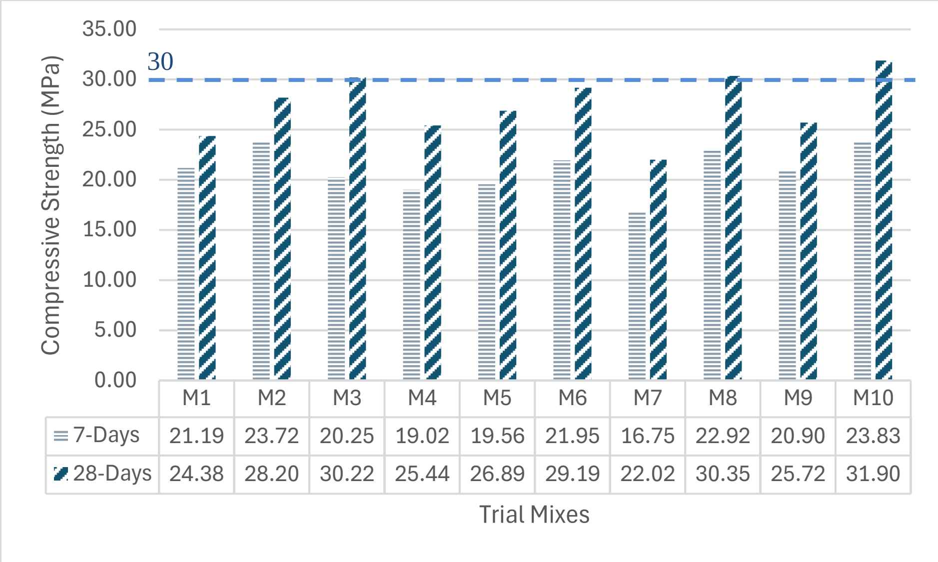


Figure 4.4: Compressive Strength of Trial Mixes.

4.3.3 Summary

In summary, the slump test and compressive strength test were conducted to evaluate the workability and compressive strength of concrete mixes with different mix proportion designs. Among the various mix proportions, Mix 10 demonstrated a favorable slump value of 102 mm, meeting the target range of 100 ± 20mm, and achieved the highest 28-day compressive strength of 31.90 MPa, surpassing the target strength of 30 MPa. Therefore, Mix 10 was selected for use as the actual mix.

4.4 Actual Mix

As concluded in the previous sections, Mix 10 was selected for the actual mix, exhibiting a slump value of 102 mm and a 28-day compressive strength of 31.90 MPa. This mix proportion was consistently used throughout the study. The detailed mix proportion design for the actual mix is provided in Table 4.3. NC-C denotes the control mix, NC-D represents the mix subjected to a delay of approximately 20-30 minutes to achieve a 50 mm slump, and NC-W refers to the mix retempered with water, where 8.82 kg/m^3 of water was found sufficient to restore the initial slump. Additionally, NC-0.05 to NC-0.3 indicate mixes retempered with superplasticizers at dosages ranging from 0.05% to 0.30% by weight of cement, in 0.05% increments.

Table 4.3: Mix Proportion of Actual Mixes.

Mix	W/C Ratio	Unit Weight (kg/m^3)				SP Retempered (%)	Water Retempered (kg/m^3)
		Cement	Water	Aggregate			
				Fine	Coarse		
NC-C/ NC-D	0.63	340	215	650	1195	-	-
NC-W	0.63	340	215	650	1195	-	8.82
NC-0.05	0.63	340	215	650	1195	0.05	-
NC-0.1	0.63	340	215	650	1195	0.10	-
NC-0.15	0.63	340	215	650	1195	0.15	-
NC-0.2	0.63	340	215	650	1195	0.20	-
NC-0.25	0.63	340	215	650	1195	0.25	-
NC-0.3	0.63	340	215	650	1195	0.30	-

4.4.1 Fresh Properties

To evaluate the fresh properties of concrete, slump tests, compacting factor tests, and vee-bee consistometer tests were performed on the mixes. Each slump test was conducted three times, with the results provided in Appendix A-5. The average slump values for the control mix (NC-C), the mix subjected to delayed casting (NC-D), and the mix retempered with water (NC-W) are presented in Figure 4.5, with the results for vebe time and compacting factor shown in Figure 4.6. According to the graphs, NC-C exhibited a slump value of 100 mm, a vebe time of 4.36 seconds, and a compacting factor of 0.92, indicating suitable mobility and compactability. In contrast, NC-D, which was left unattended until its slump value fell to approximately 50 mm, had a slump of 48 mm, a vebe time of 8.84 seconds, and a compacting factor of 0.86. This reduction in workability, as detailed in Section 2.6, was due to the ongoing hydration process forming calcium silicate hydrate, which fills the gaps between cement particles and aggregates, reducing fluidity (Alsadey, 2015). For NC-W, the addition of water improved the mixture's fluidity, restoring the slump value to 110 mm, which is slightly higher than that of NC-C and within the initial slump range of $100 \pm 20mm$. Additionally, the vebe time decreased to 4.57 seconds, and the compacting factor increased to 0.90.

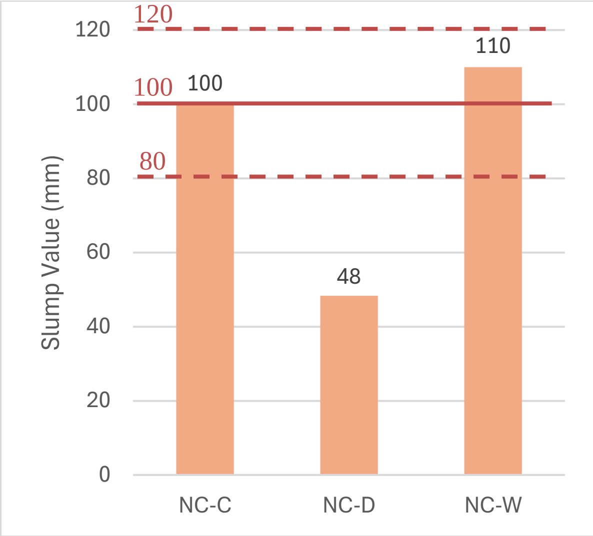


Figure 4.5: Slump Value of NC-C, NC-D, and NC-W.

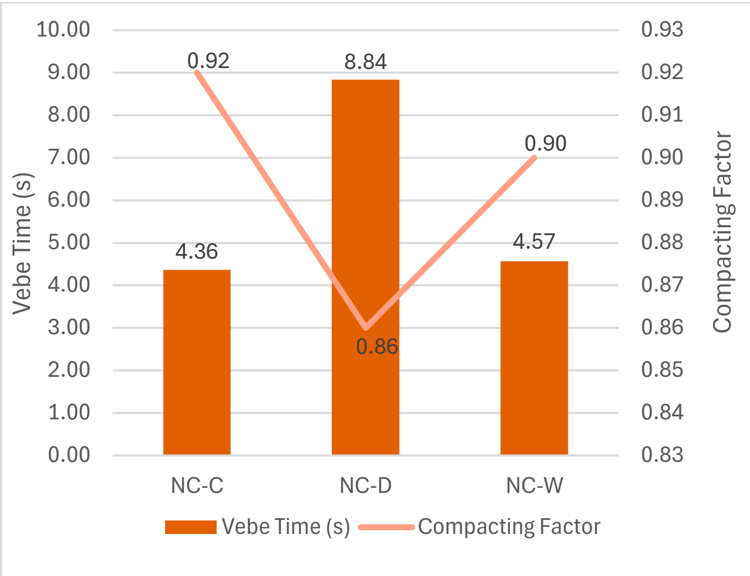


Figure 4.6: Vebe Time and Compacting Factor of NC-C, NC-D, and NC-W.

Furthermore, Figure 4.7 displays the average slump values for mixes with superplasticizer dosages of 0.05%, 0.10%, 0.15%, 0.20%, 0.25%, and 0.30%, as well as for the mix subjected to delayed casting (NC-D) for comparison. As outlined in Section 2.4.1, a superplasticizer dosage must exceed a minimum threshold, known as the critical dosage, to effectively enhance workability, with no observable effect below this level (Flatt and Schober, 2012). Figure 4.7 illustrates that a dosage of 0.05% already surpassed this critical dosage, improving the concrete's workability with a slump increase from 50 mm to 72 mm. Further increasing the dosage to 0.10% successfully restored the initial slump to 113 mm, which is within the initial slump range of 100 ± 20mm, while a subsequent increase to 0.15% continued to enhance workability, raising the slump to 162 mm. This result is consistent with the findings of research by Alsadey (2012), Alsadey and Johari (2016), and Ravindrarajah (1985), which indicate that increasing the dosage of superplasticizers leads to higher slump values.

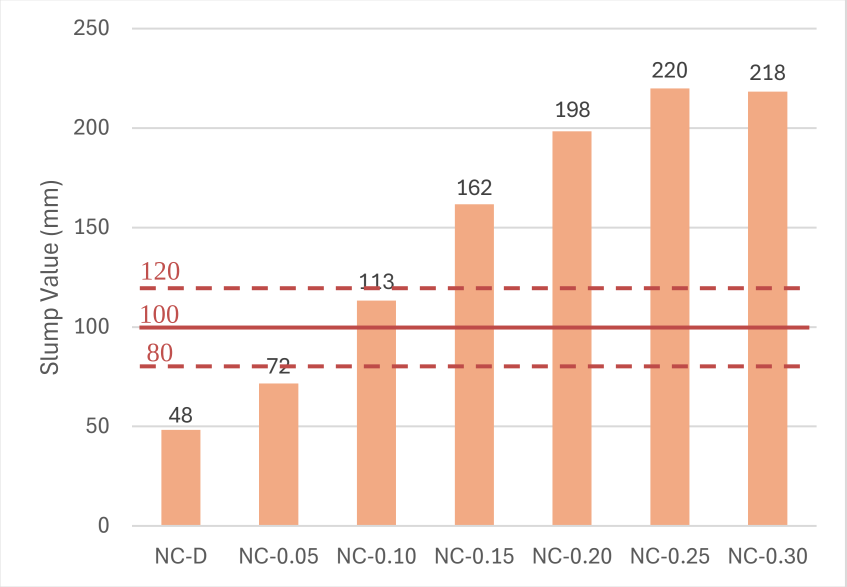


Figure 4.7: Slump Value of Mixes with Various Superplasticizer Dosages.

However, when the superplasticizer dosages reached 0.2%, 0.25% and 0.30%, the slumps were observed to be collapse slumps, with a slump value of 198mm, 220mm and 218mm respectively. This indicates that these dosages exceeded the upper limit, causing the concrete to begin segregating. Figure 4.8 illustrates the condition of the concrete with a 0.30% dosage after mixing, showing visible segregation with coarse aggregates separating from the cement paste. Additionally, bleeding was observed in the mix, as shown in Figure 4.9. This phenomenon resulted from excessive water content and inadequate viscosity in the concrete paste, which compromised its ability to retain both water and aggregates, causing the lighter water to migrate upwards and the heavier aggregates to settle (Yuan, et al., 2021).

Figure 4.8: Segregation Observed in the NC-0.30 mix.

Figure 4.9: Bleeding Observed in the NC-0.30 mix.

Moreover, Figure 4.10 shows that the results of the vee-bee consistometer test and compacting factor test were consistent with the slump test results, demonstrating improved workability as the superplasticizer dosage increases. The vebe time decreased from 8.84s to 5.26s, 4.30s, 3.90s, 2.91s, 1.98s, and 2.01s as the superplasticizer dosage increased from 0.05% to 0.10%, 0.15%, 0.20%, 0.25%, and 0.30%. Similarly, the compacting factor increased from 0.86 to 0.89, 0.92, 0.97, 0.97, 0.98, and 0.98 with the same increments in superplasticizer dosage. This result aligns with the research conducted by Sukh, Hooda, and Singh (2023), Guruswamygoud et al. (2021), and Isaac (2019), which shows that increasing the dosage of superplasticizers reduces vebe time and increases the compacting factor.

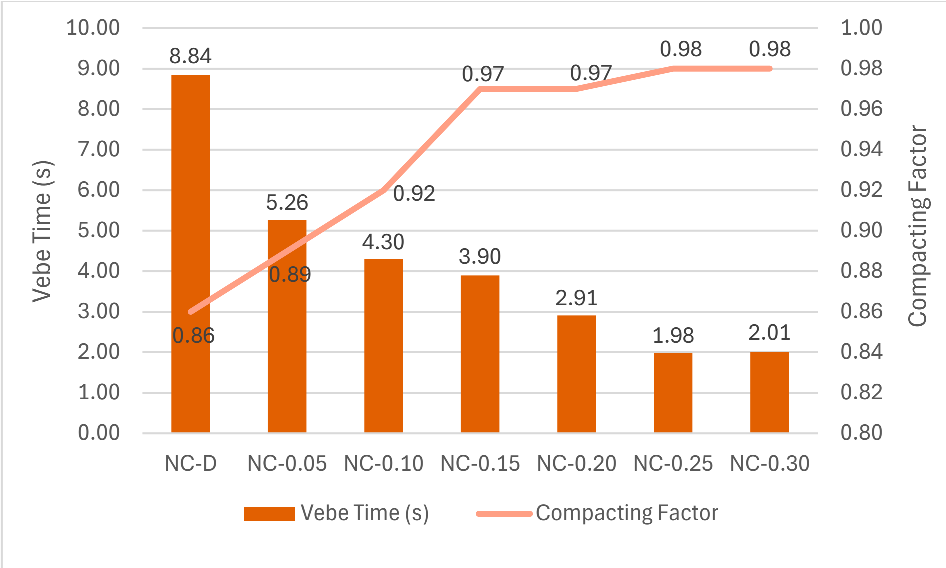


Figure 4.10: Vebe Time and Compacting Factor of Mixes with Various Superplasticizer Dosages.

Overall, the results suggest that the slump value is directly related to the compacting factor and inversely related to the vebe time. Mixes with higher workability display greater slump values and compacting factors, as well as shorter vebe times, while less workable mixes demonstrate the opposite trends. This is because more workable mixes have increased flowability, resulting in higher slump values, improved compaction, and a higher compacting factor. Moreover, the enhanced mobility and ease of compaction lead to shorter vebe times.

4.4.2 Compressive Strength

The compressive strength of the concrete mixes was assessed through compressive strength testing. The tests were conducted on 3 specimens after a 7-day curing period and on another 3 specimens after a 28-day curing period. The results of the compressive strength for these specimens are detailed in Appendix A-6. The average 7-day and 28-day compressive strengths for the NC-C, NC-D, and NC-W mixes are graphically represented in Figure 4.11.

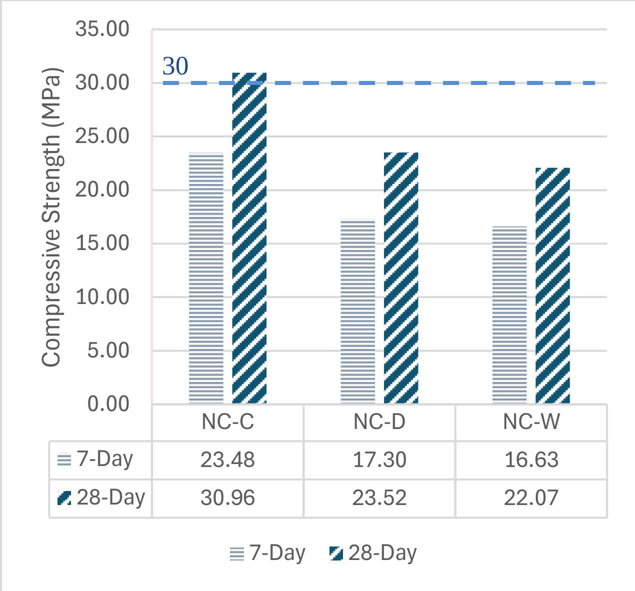


Figure 4.11: Compressive Strength of NC-C, NC-D, and NC-W.

Figure 4.11 demonstrates that NC-C achieved a 7-day strength of 23.48 MPa and a 28-day strength of 30.96 MPa. However, when the concrete mix was delayed to a slump of 50mm, NC-D showed a significant reduction in strength, with a 26.32% decrease in 7-day strength to 17.3 MPa and a 24.03% decrease in 28-day strength to 23.52 MPa. This reduction was more significant than anticipated, considering the delay was only around 20 to 30 minutes. A study by Sapkota and Mishra (2024) indicated that a significant impact on compressive strength typically occurs if casting is performed after the initial setting time, which is about 30 minutes for OPC. Additionally, as discussed in Section 2.6, the study by Mahzuz, Mehedi, and Nursat (2020) found a significant drop in compressive strength only after approximately an hour of delay, with a gradual decline leading up to that point. Nonetheless, the significant reduction was likely due to decreased workability, which made tamping and casting during placement more difficult, leading to inadequate compaction and honeycombing, ultimately reducing the concrete's strength.

On the other hand, adding water to the delayed concrete mixture resulted in the NC-W mix exhibiting reduced strength compared to NC-D, with a 3.87% decrease in 7-day strength to 16.63 MPa and a 6.16% decrease in 28-day strength to 22.07 MPa. In comparison to NC-C, the 7-day and 28-day compressive strengths have decreased by 29.17% and 28.71%, respectively. This reduction in strength was due to the addition of excess water to improve workability, which exceeded the design mixing water. With an additional 8.82 kg/m³ of water for retempering, the water-cement ratio increased from 0.63 to 0.66. This higher water-cement ratio increased the paste's porosity, which consequently led to a reduction in concrete strength (Popovics and Ujhelyi, 2008). This result is consistent with the research conducted by Erdogdu (2004) and Yousri and Seleem (2018), which demonstrated that retempering with water lowers the compressive strength of concrete.

Additionally, Figure 4.12 illustrates the average 7-day and 28-day compressive strengths for mixes with superplasticizer dosages of 0.05%, 0.10%, 0.15%, 0.20%, 0.25%, and 0.30%, along with the mix subjected to delayed casting (NC-D) for comparison. It was observed that the 7-day compressive strength increased from 17.30 MPa to 21.92 MPa, 25.22 MPa, and 27.09 MPa as the superplasticizer dosage increased from 0%, 0.05%, and 0.10% to 0.15%. However, the compressive strength began to decrease to 26.71 MPa, 24.03 MPa, and 24.32 MPa as the dosage was further increased to 0.20%, 0.25%, and 0.30%. A similar trend was observed for the 28-day compressive strength, which increased from 23.52 MPa to 28.76 MPa, 31.62 MPa, and 33.57 MPa as the dosage increased from 0%, 0.05%, and 0.10% to 0.15%. However, the strength decreased to 29.86 MPa, 25.93 MPa, and 26.78 MPa as the dosage was further increased to 0.20%, 0.25%, and 0.30%.

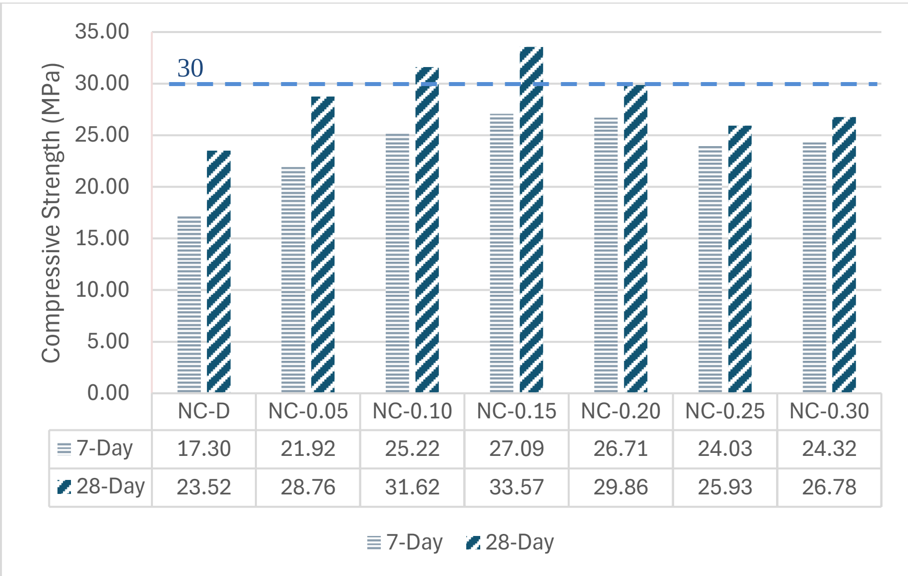


Figure 4.12: Compressive Strength of Mixes with Various Superplasticizer Dosages.

The increase in compressive strength with the rise in superplasticizer dosage from 0.05% to 0.15% was likely due to improved workability, resulting from the superplasticizers' effect. Higher dosages release entrapped water by deflocculating cement particles, promoting better hydration (Alsadey, 2015). Additionally, improved workability leads to better compaction of the concrete, enhancing its strength. The presence of the superplasticizer also allowed more time for the aggregates to absorb water. This increased water absorption by the aggregates led to a lower water-cement ratio, further boosting compressive strength (Sobhani, Najimi, and Pourkhorshidi, 2012). This result is consistent with the findings of Erdogdu (2004) and Sobhani, Najimi, and Pourkhorshidi (2012), which showed that retempering with superplasticizer improves compressive strength. It also aligns with the research by Alsadey (2015), which demonstrated that compressive strength increases with higher superplasticizer dosages.

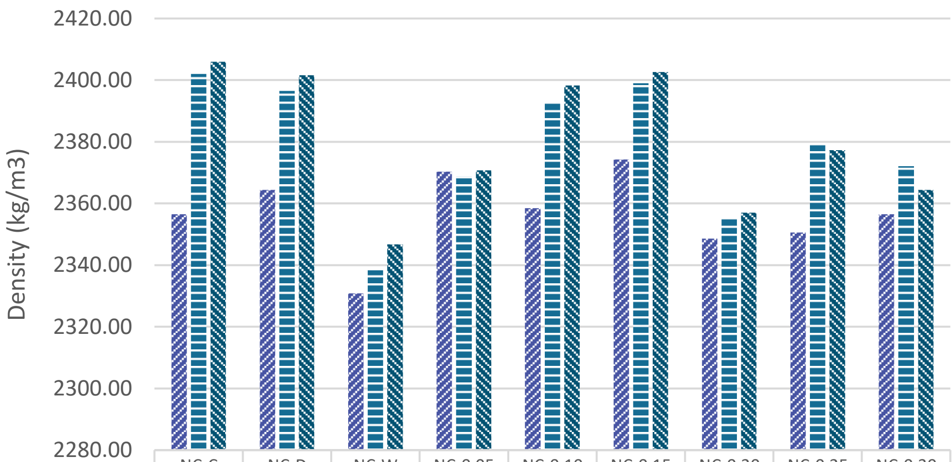
On the other hand, the decrease in compressive strength at dosages starting from 0.2% was attributed to bleeding and segregation caused by overdosing. As discussed in Section 4.4.1, segregation led to lighter water rising to the surface and heavier aggregates settling. The upward-moving bleed water may have been trapped by the aggregate, forming numerous bleed-water pockets, while the settling aggregates could result in honeycombing (Yuan, et al., 2021). This compromised the concrete's cohesiveness and uniformity, ultimately reducing its strength. This study again aligns with Alsadey's (2015) research, which found that excessive superplasticizer dosage leads to a reduction in compressive strength. Figure 4.13 illustrates the observed honeycombing in a specimen of the NC-0.25 mix.

Figure 4.13: Observed Honeycombing in NC-0.25 Specimen.

Overall, Among the six superplasticized mixes, only NC-0.1 and NC-0.15 exceeded the NC-C 28-day compressive strength of 30.96 MPa, with increases of 2.13% and 8.43%, respectively. However, all mixes surpassed the NC-D 28-day strength of 23.52 MPa, even those exhibiting segregation, with improvements of 22.28%, 34.44%, 42.73%, 26.96%, 10.25%, and 13.86% for NC-0.05, NC-0.1, NC-0.15, NC-0.2, NC-0.25, and NC-0.3, respectively. Notably, NC-0.15 achieved the highest 28-day strength of 33.57 MPa, marking it as the optimal dosage for ensuring uniformity and proper compaction. Dosages below this level may result in inadequate compaction, while those above it risk segregation.

4.4.3 Density

The density of all the mixes in their fresh, 7-day, and 28-day hardened states was tested, with the results presented in Appendix A-7. Figure 4.14 presents a graph of the average fresh, 7-day, and 28-day densities of the mixes. It can be observed that the NC-D mix had a fresh density 0.34% higher than the NC-C mix, indicating a slightly more compact mixture. Notably, the NC-0.15 mix displayed the highest fresh density, likely due to effective compaction achieved with the appropriate amount of superplasticizer, resulting in denser concrete. In contrast, the NC-W mix had the lowest fresh density, as the addition of extra water led to a less compact mixture. While there is no clear trend in fresh density with increasing superplasticizer dosage, it is apparent that mixes exhibiting segregation (NC-0.2, NC-0.25, and NC-0.3) had relatively lower fresh densities compared to other superplasticized mixes, suggesting reduced compactability when segregation occurs.



	NC-C	NC-D	NC-W	NC-0.05	NC-0.10	NC-0.15	NC-0.20	NC-0.25	NC-0.30
Fresh Density	2356.54	2364.44	2330.86	2370.37	2358.52	2374.32	2348.64	2350.62	2356.54
7-Day Density	2402.02	2396.49	2338.31	2368.78	2392.53	2399.06	2355.46	2379.32	2372.10
28-Day Density	2405.92	2401.55	2346.79	2370.76	2398.24	2402.67	2357.04	2377.34	2364.42

Figure 4.14: Fresh and Hardened Density of All Mixes.

Most of the mixes demonstrated an increase in density from their fresh state to their 7-day hardened state, with the exception of the NC-0.05 mix, which showed a 0.07% decrease. The NC-C mix exhibited the highest 7-day density growth at 1.93%, followed by NC-0.1, NC-D, NC-0.25, NC-0.15, NC-0.3, NC-W and NC-0.2, with growth rates of 1.44%, 1.36%, 1.22%, 1.04%, 0.66%, 0.32%, and 0.29% respectively. Similarly, most of the mixes showed an increase in density from their 7-day to their 28-day hardened state, except for the NC-0.25 and NC-0.3 mixes, which exhibited decreases of 0.08% and 0.32%, respectively. The NC-W mix experienced the highest 28-day density growth at 0.36%, followed by NC-0.1, NC-D, NC-C, NC-0.15, NC-0.05 and NC-0.2, with growth rates of 0.24%, 0.21%, 0.16%, 0.15%, 0.08% and 0.07%, respectively.

The increase in density as curing age progresses may be attributed to the formation of dense calcium silicate hydrate (C-S-H) gel, which fills the voids in the concrete as it undergoes hydration, thereby contributing to an increase in weight. Additionally, the increase could be due to the reduction in volume as the concrete cures, as it tends to shrink when excess water not used in hydration gradually evaporates from the hardened mix. Conversely, the decrease in density observed in some mixes might be due to a reduction in concrete weight caused by the escape of air and excess water during the curing and hardening process.

4.4.4 Air Content

The air content for all the mixes was calculated using a formula and plotted in graphs. Figure 4.15 illustrates the results for the NC-C, NC-D, and NC-W mixes, while Figure 4.16 shows the superplasticized mixes, with the NC-D mix included for comparison. In Figure 4.15, it was observed that the NC-D mix had 18.23% lower air content compared to the NC-C mix, decreasing from 1.81% to 1.48%. Conversely, the NC-W mix exhibited a 94.59% higher air content compared to the NC-D mix, rising from 1.48% to 2.88%. In Figure 4.16, the air content increased with the addition of 0.1%, 0.2%, 0.25%, and 0.3% superplasticizer, rising from 1.48% to 1.73%, 2.14%, 2.06%, and 1.81%, representing increases of 16.89%, 44.59%, 39.19%, and 22.3%, respectively. However, the air content decreased when 0.05% and 0.15% superplasticizer were added, dropping from 1.48% to 1.23% and 1.07%, representing decreases of 16.89% and 27.7%, respectively.

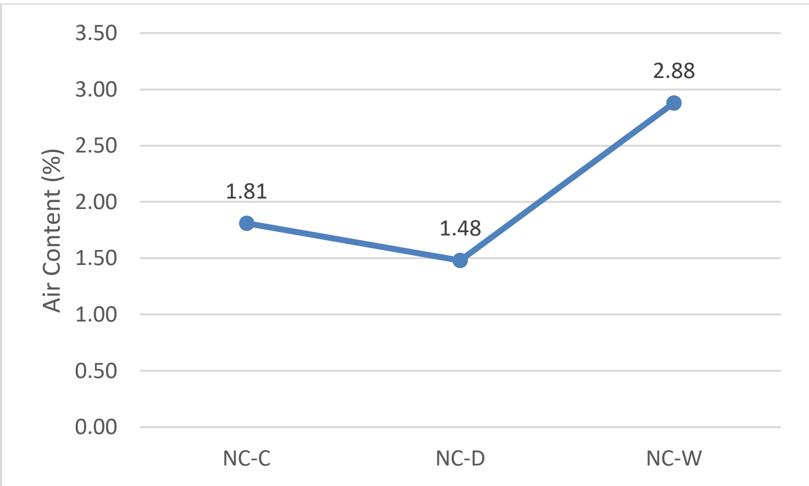


Figure 4.15: Air Content of NC-C, NC-D and NC-W.

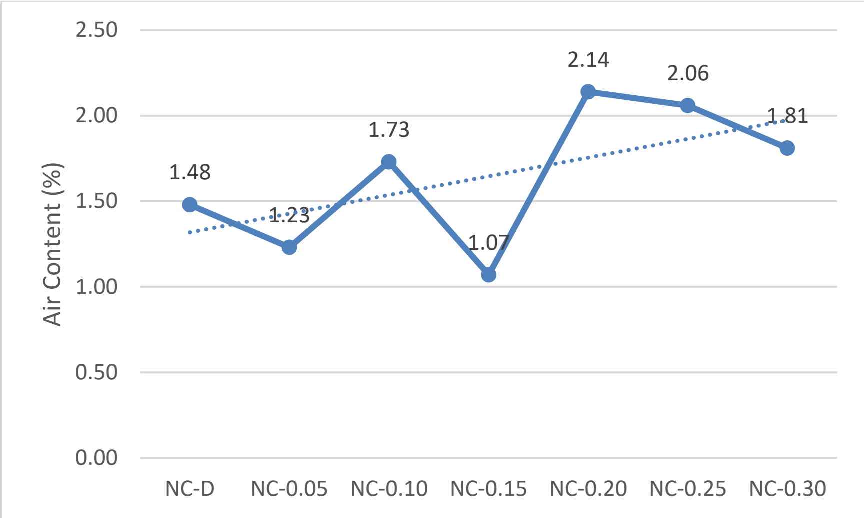


Figure 4.16: Air Content of Mixes with Various Superplasticizer Dosages.

The trend in air content can be attributed to its inverse relationship with the fresh density of concrete; that is, denser concrete is typically better compacted and contains less entrapped air. Although there is no clear trend in air content with increasing superplasticizer dosage, a trendline on the graph indicates that air content generally increases with higher superplasticizer levels. However, this increase may be due to the poor compaction of segregated concrete in mixes NC-0.2, NC-0.25, and NC-0.3, leading to lower density and higher air content. Overall, adding superplasticizer tends to increase air content, except for mixes NC-0.05 and NC-0.15, which aligns with the theory proposed by Flatt and Schober (2012) that superplasticizers can raise air content in concrete mixes.

Figure 4.17 presents the relationship between air content and 28-day compressive strength for all mixes. Compared to the control mix (NC-C), the air content in NC-W, NC-0.2, and NC-0.25 is higher by 1.07%, 0.33%, and 0.25%, respectively, with corresponding reductions in compressive strength of 28.71%, 3.55%, and 16.25%. Conversely, NC-0.1 and NC-0.15 show lower air content by 0.08% and 0.74% compared to NC-C, along with increases in compressive strength of 2.13% and 8.43%, respectively. This trend can be attributed to the fact that higher air content increases concrete porosity, and hence reducing compressive strength. In general, compressive strength tends to decrease by around 5% for each 1% increase in air content (Holan, et al.,2020). However, this pattern is not observed in the mixes NC-D, NC-0.05, and NC-0.3, suggesting that the relationship between air content and compressive strength may not be consistent across all mixes.

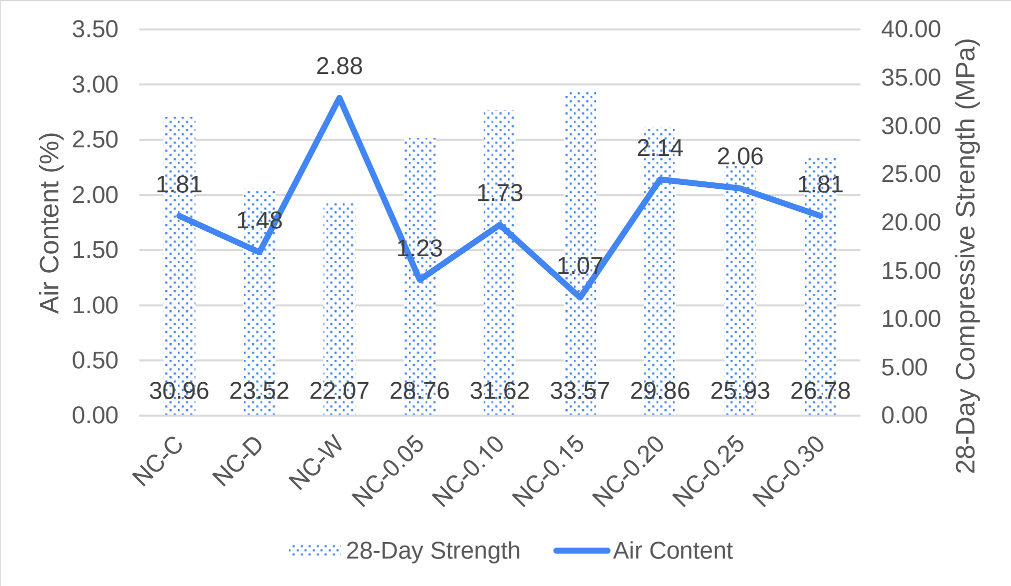


Figure 4.17: Relationship Between Air Content and 28-day Compressive Strength For All Mixes.

4.4.5 Summary

In summary, the fresh and hardened properties of NC-C, NC-D, NC-W, NC-0.05, NC-0.1, NC-0.15, NC-0.2, NC-0.25, and NC-0.3 were investigated and analysed. It was found that the workability of concrete improves with increasing superplasticizer dosage, with a dosage of 0.1% being sufficient to restore the initial slump of 100 mm and 0.15% achieving the highest slump before segregation occurs. Regarding compressive strength, the NC-D mix experienced a 24.03% reduction, decreasing from 30.96 MPa in NC-C to 23.52 MPa. The NC-W mix showed a further 6.16% decrease in 28-day strength, dropping to 22.07 MPa compared to NC-D. Among the superplasticized mixes, NC-0.15 achieved the highest 28-day compressive strength at 33.57 MPa, representing a 42.73% increase over the NC-D mix. Mixes with dosages below and above this level showed relatively lower strength, likely due to inadequate compaction and segregation. Overall, all superplasticized mixes surpassed the NC-D 28-day strength of 23.52 MPa, but only NC-0.1 and NC-0.15 exceeded the NC-C 28-day strength of 30.96 MPa. Lastly, the density of the mixes was tested, with NC-0.15 having the highest fresh density and NC-W the lowest, attributed to their compaction levels. The air content was also computed, showing an inverse relationship with fresh density and suggesting that air content increases with the addition of superplasticizer. Additionally, lower air content was found to lead to higher strength in concrete mixes, though this result is not consistent across all mixes.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the analysis of the results from various laboratory tests, several conclusions can be drawn to fulfill the objectives of this study.

The first objective of this study is to compare the fresh properties of untreated concrete, concrete treated with water addition, and concrete treated with high-range superplasticizer. It was observed that the concrete's slump decreased after a 20-30 minute delay, indicating reduced workability when the concrete was left unattended. However, retempering with an adequate amount of extra water restored the slump, demonstrating that water addition can improve workability. Additionally, re-dosing with superplasticizer showed that increasing the dosage enhances workability, with 0.1% being sufficient to restore the slump and 0.15% achieving the highest slump before segregation occurs. Moreover, the density test revealed that NC-0.15 had the highest fresh density, followed by NC-0.05, NC-D, NC-0.1, NC-C, NC-0.3, NC-0.25, NC-0.2, and NC-W, indicating better compaction with improved workability due to the appropriate amount of superplasticizer, while excessive water and segregation resulted in poorer compaction. Air content was inversely related to fresh density.

The second objective of this study is to compare the hardened properties of untreated concrete, concrete treated with water addition, and concrete treated with high-range superplasticizer. A 24.03% decrease in 28-day compressive strength was observed when the concrete mix was subjected to delayed casting. Retempering with water resulted in an additional 6.16% reduction in strength compared to NC-D, demonstrating that water retempering is not a good practice as it leads to significant strength reduction. In contrast, among the concrete mixes re-dosed with various superplasticizer dosages, the 0.15% dosage achieved the highest compressive strength, with a 42.73% increase compared to NC-D, followed by dosages of 0.1%, 0.2%, 0.05%, 0.3%, and 0.25%. While only the 0.15% and 0.1% dosages exceeded the compressive strength of NC-C, all superplasticized mixes surpassed the strength of NC-D, highlighting the positive impact of superplasticizer on compressive strength. Thus, retempering with an appropriate amount of superplasticizer is concluded to be a more favorable method than retempering with water from a compressive strength perspective.

The third objective of this study is to determine the optimal dosage of high-range superplasticizer required for re-dosing to regain the original slump of grade 30 concrete due to delay casting. The optimal dosage for regaining the slump was found to be 0.1%, which also provided a compressive strength of 31.62 MPa, surpassing NC-D's 28-day strength by 31.63% and NC-C's by 2.13%. Additionally, the dosage achieving the best balance of workability and compressive strength was 0.15%, resulting in a slump of 162 and a compressive strength of 33.57 MPa, exceeding NC-D's 28-day strength by 42.73% and NC-C's by 8.43%. This dosage is deemed optimal for achieving the best uniformity and compaction of the concrete, as lower dosages may lead to insufficient compaction while higher dosages risk segregation.

5.2 Recommendations for Future Work

The following recommendations could be considered to improve study outcomes and enhance the validity, reliability, and feasibility of the data gathered in this research..

1. For more accurate and precise results, additional dosages should be tested at smaller intervals, allowing the exact optimum dosage for the mix to be determined by plotting a best-fit curve.
2. In this study, compressive strength is only measured at 7 and 28 days. Further research could explore early and long-term strength at 1, 3, or 56 days to provide a clearer understanding of initial strength development and to assess whether the concrete continues to gain strength beyond 28 days.
3. Since different types of admixtures can react differently when in contact with cement, even within the same category, further studies can be conducted on a broader range of admixtures to assess which ones show more favorable performance under similar conditions.
4. Given that the optimal dosage for restoring slump and balancing workability and strength varies with each concrete mix due to

differences in composition, developing an estimation model or equation to identify the appropriate amount of superplasticizer for redosing would be beneficial for reducing trial-and-error adjustments.

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APPENDICES

Appendix A: Tables

Appendix A- 1: Result of Sieve Analysis for Fine Aggregate.

Sieve Size (mm)	Weight (kg)			Percentage of Aggregate Retained on Each Sieve (%)	Cumulative Percentage		Grading Requirements for Total Percent Passing according to ASTM C33 (%)
	Empty Sieve	Sieve with Aggregate Retained	Aggregate Retained on Each Sieve		Coarser (%)	Finer (%)	
9.5	0.44	0.44	0.00	0.00	0.00	100.00	100
4.75	0.49	0.49	0.00	0.00	0.00	100.00	95 to 100
2.36	0.47	0.49	0.02	1.83	1.83	98.17	80 to 100
1.18	0.47	0.66	0.19	17.43	19.27	80.73	50 to 85
0.6	0.34	0.58	0.24	22.02	41.28	58.72	25 to 60
0.3	0.37	0.74	0.37	33.94	75.23	24.77	5 to 30
0.15	0.37	0.60	0.23	21.10	96.33	3.67	0 to 10
Pan	0.25	0.29	0.04	3.67	100.00	0.00	-
Total			1.09	100.00			

Appendix A- 2: Result of Sieve Analysis for Coarse Aggregate.

Sieve Size (mm)	Weight (kg)			Percentage of Aggregate Retained on Each Sieve (%)	Cumulative Percentage		Grading Requirements for Total Percent Passing according to ASTM C33 (%)
	Empty Sieve	Sieve with Aggregate Retained	Aggregate Retained on Each Sieve		Coarser (%)	Finer (%)	
25	0.40	0.40	0.00	0.00	0.00	100.00	100
20	0.44	0.45	0.01	1.01	1.01	98.99	90 to 100
9.5	0.44	1.22	0.78	78.79	79.80	20.20	20 to 55
4.75	0.49	0.66	0.17	17.17	96.97	3.03	0 to 10
Pan	0.25	0.28	0.03	3.03	100.00	0.00	-
Total			0.99	100.00			

Appendix A- 3: Result of Slump Value for Trial Mix.

Trial Mixes	**Slump Value (mm)**		
	1	**2**	**3**
M1	0	0	0
M2	40	45	40
M3	160	145	150
M4	180	170	180
M5	135	140	130
M6	145	135	140
M7	125	145	140
M8	120	110	120
M9	50	55	50
M10	90	105	110

Appendix A- 4: Result of Compressive Strength for Trial Mix.

Trial Mixes	**Compressive Strength (MPa)**					
	7 days			**28 days**		
	1	**2**	**3**	**1**	**2**	**3**
M1	21.12	17.89	24.57	24.71	19.51	28.91
M2	22.60	20.42	28.14	29.94	30.14	24.52
M3	19.12	16.75	24.89	30.61	31.11	28.93
M4	18.83	17.55	20.67	25.23	25.04	26.04
M5	20.54	18.71	19.44	26.29	26.52	27.85
M6	22.79	20.96	22.11	28.44	30.85	28.27
M7	15.30	18.70	16.26	22.72	23.25	20.08
M8	24.86	23.36	20.54	31.20	30.25	29.59
M9	20.16	21.28	21.26	26.22	23.95	26.99
M10	23.17	24.53	23.80	31.72	31.07	32.90

Appendix A- 5: Result of Slump Value for Actual Mix.

Actual Mixes	Slump Value (mm)		
	1	2	3
NC-C	110	85	105
NC-D	50	55	40
NC-W	120	100	110
NC-0.05	70	80	65
NC-0.10	105	115	120
NC-0.15	160	165	160
NC-0.20	200	205	190
NC-0.25	220	220	220
NC-0.30	220	215	220

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

Actual Mixes	Compressive Strength (MPa)					
	7 days			28 days		
	1	2	3	1	2	3
NC-C	22.90	24.03	23.50	31.08	31.33	30.48
NC-D	18.38	17.31	16.22	24.57	22.33	23.66
NC-W	16.80	16.75	16.33	22.99	21.89	21.33
NC-0.05	22.18	20.82	22.77	28.13	28.94	29.22
NC-0.10	26.92	23.56	25.17	31.67	29.72	33.47
NC-0.15	28.63	26.61	26.03	33.18	32.5	35.04
NC-0.20	25.80	27.29	27.04	30.86	31.06	27.67
NC-0.25	24.22	22.81	25.06	26.21	24.62	26.96
NC-0.30	25.11	22.90	24.94	26.51	25.9	27.92

Appendix A- 7: Result of Fresh and Hardened Density of Actual Mixes.

Mix	Curing Period	Sample	Volume	Weight	Density	Average Density
NC-C	Fresh	1	0.00338	7.92	2370.37	2356.54
		2	0.00338	7.94	2352.59	
		3	0.00338	8	2346.67	
	7 day	1	0.00333	7.98	2396.36	2402.02
		2	0.00332	8	2407.14	
		3	0.00335	8.06	2402.56	
	28 day	1	0.00332	7.98	2402.79	2405.92
		2	0.00332	8	2408.76	
		3	0.00334	8.04	2406.22	
NC-D	Fresh	1	0.00338	7.98	2376.30	2364.44
		2	0.00338	8.02	2352.59	
		3	0.00338	7.94	2364.44	
	7 day	1	0.00337	8	2375.48	2396.49
		2	0.00334	8.04	2409.66	
		3	0.00332	7.98	2404.33	
	28 day	1	0.00335	7.98	2380.55	2401.55
		2	0.00332	8.02	2414.95	
		3	0.00331	7.98	2409.16	
NC-W	Fresh	1	0.00338	7.86	2328.89	2330.86
		2	0.00338	7.86	2328.89	
		3	0.00338	7.88	2334.81	
	7 day	1	0.00336	7.86	2340.03	2338.31
		2	0.00335	7.82	2334.77	
		3	0.00335	7.84	2340.14	
	28 day	1	0.00334	7.84	2344.95	2346.79
		2	0.00331	7.82	2359.69	
		3	0.00335	7.82	2335.73	
NC-0.05	Fresh	1	0.00338	7.96	2358.52	2370.37
		2	0.00338	8.04	2382.22	
		3	0.00338	8	2370.37	

		1	0.00336	7.96	2367.98	
	7 day	2	0.00337	7.98	2369.18	2368.78
		3	0.00337	7.98	2369.18	
		1	0.00336	7.96	2367.98	
	28 day	2	0.00337	8	2375.12	2370.76
		3	0.00337	7.98	2369.18	
		1	0.00338	7.92	2346.67	
	Fresh	2	0.00338	8	2370.37	2358.52
		3	0.00338	7.96	2358.52	
		1	0.00337	7.98	2369.18	
NC-0.1	**7 day**	2	0.00331	8.02	2424.52	2392.53
		3	0.00334	7.96	2383.91	
		1	0.00336	7.98	2373.93	
	28 day	2	0.00331	8.02	2424.52	2398.24
		3	0.00333	7.98	2396.27	
		1	0.00338	8.02	2376.30	
	Fresh	2	0.00338	8.02	2376.30	2374.32
		3	0.00338	8	2370.37	
		1	0.00335	8.04	2403.05	
NC-0.15	**7 day**	2	0.00336	8.04	2391.78	2399.06
		3	0.00333	8	2402.35	
		1	0.00334	8.04	2407.86	
	28 day	2	0.00336	8.04	2391.78	2402.67
		3	0.00333	8.02	2408.35	
		1	0.00338	7.92	2346.67	
	Fresh	2	0.00338	7.9	2340.74	2348.64
		3	0.00338	7.96	2358.52	
		1	0.00337	7.9	2345.43	
NC-0.2	**7 day**	2	0.00337	7.92	2351.37	2355.46
		3	0.00336	7.96	2369.58	
		1	0.00337	7.9	2345.43	
	28 day	2	0.00337	7.92	2351.37	2357.04
		3	0.00335	7.96	2374.33	

		1	0.00338	7.92	2346.67	
	Fresh	2	0.00338	7.9	2340.74	2350.62
		3	0.00338	7.98	2364.44	
		1	0.00331	7.94	2400.33	
NC-0.25	**7 day**	2	0.00337	7.92	2351.37	2379.32
		3	0.00335	8	2386.26	
		1	0.00331	7.94	2400.33	
	28 day	2	0.00337	7.9	2345.43	2377.34
		3	0.00335	8	2386.26	
		1	0.00338	7.98	2364.44	
	Fresh	2	0.00338	7.92	2346.67	2356.54
		3	0.00338	7.96	2358.52	
		1	0.00337	8	2375.12	
NC-0.3	**7 day**	2	0.00336	7.94	2362.03	2372.10
		3	0.00335	7.96	2379.14	
		1	0.00337	7.96	2363.25	
	28 day	2	0.00336	7.94	2362.03	2364.42
		3	0.00336	7.96	2367.98	