EXPERIMENTAL INVESTIGATION OF WATER QUALITY IMPACT ON THE COMPRESSIVE STRENGTH OF CONCRETE

by

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DISSERTATION

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DEDICATION

Words cannot express the extent of my deep appreciation for my father, Mohammad Reza, my mother, Leila, my sister, Sheila, my aunts, my uncle, and all my family members for teaching me some of the most important lessons to be learned about character, dignity, and integrity. They selflessly encouraged me to explore new directions in life and seek my own destiny. Without their sacrifice, endless support, and blessing, this achievement would have remained only a dream.

Abstract

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Water is an indispensable component in concrete, as it enables crucial chemical reactions. Therefore, the quality of water used in concrete plays a vital role in its performance. Contaminated water, sewage, or high-salt water can disrupt the cement's setting process and overall performance. As a result, it is crucial to prioritize the use of drinking water or water of equivalent quality in concrete production. While the ideal water-to-cement ratio for concrete is typically around 0.20, practical considerations often require a higher water content ranging from 0.30 to 0.70. This increased water consumption is necessary to ensure workability and achieve optimal concrete performance.

Notably, existing research lacks investigation into the combined effects of total dissolved solids (TDS) concentrations and pH values on concrete. Although previous studies have focused on the effects of sodium chloride on concrete performance, particularly regarding corrosion, none have simultaneously examined the effects of TDS concentrations at different pH levels. Furthermore, even though current research articles discuss suitable water quality for concrete production in general, a need still exists to statistically validate specific ranges of water quality parameters through laboratory investigations.

This dissertation investigates the minimum acceptable compressive strength of concrete under varying concentrations of total dissolved solids (TDS) in both alkaline and acidic environments. The primary objective is to examine the impact of different TDS concentrations on the compressive strength of concrete across different pH ranges. The secondary objective is to identify the maximum permissible TDS concentrations that can ensure the desired compressive strength.

This experimental investigation follows a methodology to examine the effects of TDS concentrations and pH levels on the compressive strength of concrete. Concrete samples are prepared using different TDS concentrations, including 1,000 ppm, 2,000 ppm, and 3,000 ppm, up to 4,000 ppm, while pH levels are controlled at 6 and 8. A total of 102 specimens were cast and cured for 3 days, 7 days, and 28 days. The compressive strengths of the concrete samples were measured at regular intervals to assess the influence of TDS and pH on the performance of the concrete.

In conclusion, this research addresses a critical gap in the literature by investigating the combined effects of TDS concentrations and pH levels on the compressive strength of concrete. By statistically validating specific ranges of quality parameters through laboratory investigations, the study aims to provide practical insights into the maximum permissible TDS concentration that ensures the desired compressive strength. The results of this research will contribute to a better understanding of the influence of water quality on concrete compressive strength and help guide the development of sustainable concrete production practices. Due to limited time and resources, this dissertation does not provide conclusive results, but provides an insight for possible utilization of non-drinking water for concrete mix design without sacrificing its compressive strength.

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Chapter 1 Introduction

1.1. Background

Concrete is widely recognized as one of the most extensively used construction materials worldwide, owing to its accessibility, durability, and cost-effectiveness.Its indispensable role in both reinforced and unreinforced structural elements has become rooted in our perception of modern construction practices (Ashraf, 2012; Mehta, 2014).

Over time, concrete has gained significant popularity and is the prevailing construction material of choice (Ashraf, 2012). Notably, concrete consumption surpasses that of any other material, second only to water. On average, three tons of concrete are utilized per person each year, making it twice as prevalent in construction compared to all other building materials combined (Gagg, 2014). To ensure optimal performance, concrete constituents must be carefully selected, adhering to design criteria for safety, structural integrity, and aesthetic appearance, while considering environmental factors (Mehta, 2014).

Among these constituents, water plays a crucial role as it facilitates chemical reactions in concrete. Therefore, the quality of water used in concrete is of paramount importance, as impurities can significantly impact cement setting and overall performance (Elaty et al., 2014). It is imperative to avoid the use of contaminated water, sewage, or high-salt content in water, emphasizing the preference for drinking water or water of equivalent quality (Elaty et al., 2014).

Theoretically, the water-to-cement ratio in concrete should be around 20% by weight, but in practice, a higher water consumption ranging from 30% to 55% is often required to achieve the desired slump (Rawa et al., 2012). Water quality plays a vital role in concrete production as it can have significant implications on various aspects, including setting time, strength development, and potential staining of the concrete. Although natural waters, freshwater sources, and treated urban water supplies are generally considered suitable for concrete mixing, it is essential to ensure they are free from odors or tastes. Surprisingly, the attention given to water quality in concrete production is often inadequate, despite thorough inspections of other components, such as cement and aggregates (Lamond et al., 2006).

This dissertation addresses the significance of water quality in concrete and its impact on concrete durability and performance by investigating the effects of different water sources, water impurities, and water-to-cement ratios on concrete properties. Through laboratory experiments and investigation, this dissertation provides insights into optimizing water usage in concrete production while adhering to established standards and enhancing sustainability.

1.1.1 Definitions

In this section, the conceptual and operational definitions of key terms and concepts related to this dissertation are provided. This ensures clarity and consistency in understanding throughout the dissertation

1.1.1.1 Concrete

- In a general sense, concrete refers to any substance or compound formed by a cohesive material with cementitious properties. This cohesive material is typically the result of the interaction between hydraulic cement and water. Concrete can be prepared using various types of cement, as well as pozzolans, furnace slag, additives, sulfur, polymers, fibers, and other materials. Additionally, the construction of concrete may involve the use of heat, steam, autoclaves, vacuum, hydraulic pressure, and various compaction techniques (Neville, 2010).

In this dissertation, concrete samples were produced using different mixture designs based on compressive strength tests conducted at The University of Texas at Arlington. All samples were made from moderate sulfate resistant ASTM C150 C150M-22 Type 2 Portland cement (ASTM 2022) to study its specific characteristics' effects on enhancing the durability and performance of concrete mix designs.

1.1.1.2 Concrete Mix Design

- Determining the concrete mixture design, or determining the proportions of concrete constituents, is a process through which the correct combination of cement, aggregates, water, and additives is achieved to produce concrete according to the specified requirements. Although several precise technical principles have been documented for concrete mixture design, it has been established that these procedures are not solely based on scientific foundations for several reasons and are mostly considered as empirical art (Irandoost, 2013;). The concrete mixture designs used for producing concrete samples used a water-to-cement ratio of 0.6 and 0.4, combined with other constituents.

1.1.1.3 Water

- In general, water used in concrete construction should be suitable for drinking. Water can be considered suitable for concrete construction if it meets the following conditions:
  - It should not be acidic or alkaline.

- The percentage of sulfates should be less than 1.0%.
- The percentage of chlorides should be less than 0.5%.
- It should contain less than 1.0% carbonates.
- It should have less than 1.0% suspended particles.

Generally, water that is suitable for concrete construction will also be easy to handle. However, the presence of iron and organic materials in water can cause staining on the concrete surface, particularly when the water flows over the concrete surface slowly and evaporates quickly. In some cases, the appearance of the concrete is not critical. In other words, the water quality is slightly lower than ideal for the concrete mixture but can still be accepted. Overall, it is recommended that water used for concrete construction be free from substances that may have an adverse effect on the hardened concrete, such as water containing free CO_2 (Timourtash, 2018).

The control samples were prepared using drinking water sourced from The University of Texas at Arlington, while the water for the test samples was specifically prepared using water from a local Arlington supply, ensuring the desired total dissolved solids (TDS) and pH levels were achieved.

1.1.1.4 Portland Cement

- According to ASTM C150/-22 (ASTM 2022), Portland cement is a type of hydraulic cement produced by pulverizing clinker, primarily composed of silicates, aluminates, and ferrites, which are responsible for the formation of silicate and aluminate compounds in Portland cement. Concrete samples with various mixture designs based on compressive strength tests were prepared in the Structural Materials Laboratory of

The University of Texas at Arlington. All samples were cured in similar water conditions, and the testing duration for sample fractures was 3, 7, and 28 days.

1.1.1.5 Aggregates

Rock materials can be classified into two categories: coarse aggregates (stone) and fine aggregates (sand). Aggregate materials (stone and sand) typically occupy 60% to 75% of the volume of concrete, with 60% to 70% consisting of stone particles and 30% to 40% composed of sand particles. The role of aggregates is to provide the concrete skeleton, which the strength of concrete depends on. Aggregate materials can be obtained in two forms: natural aggregate materials and crushed aggregate materials. Natural aggregates are sourced from riverbeds and have rounded or spherical shapes, while crushed aggregates are produced by crushing larger rocks using crushing machines. Crushed aggregates have sharp-edged particles and rough surfaces, which provide better adhesion to cement, making them more suitable for preparing concrete. The size of aggregates is based on particle diameter, according to ASTM C33/C33M-18 (ASTM 2018). The diameter of stone particles ranges from 2 mm to 2.76 mm, while the diameter of sand particles varies from 0.075 mm to 2 mm according to the ASTM D2487-17-e1 (ASTM 2020) and parameters defined by Irandoost (2013) and Brady and Weil (2008).

In this study, coarse and fine aggregate materials were used for producing concrete samples with various mixture designs based on compressive strength tests obtained from Sakrete of North America LLC (2023). Data sheets on both the purchased sand and gravel are in the Appendix (pages 195, 196) . The aggregate materials obtained from the quarry had irregular broken, and angular appearances, lacking long and flat particles, with a compact and non-porous grain structure. These aggregate materials alone exhibited satisfactory strength, which gave the aggregate phase of this dissertation project good concrete strength properties throughout testing.

1.2 Problem Statement

The urgent need for a solution to the water problem addressed in this dissertation arises from a confluence of factors, including climate change, rapid population growth, escalating surface and groundwater pollution, unequal distribution of water resources, and recurring challenges posed by droughts. These pressing issues have compelled experts to explore innovative approaches to secure reliable water supplies and enhance water use efficiency. As a result, there is a growing interest in investigating alternative water sources for concrete production, with a particular focus on harnessing the potential use of brackish water, ocean water, and seawater, which can offer a potential solution to reducing the strain on freshwater reserves while promoting environmentally friendly concrete manufacturing practices.

Brackish water refers to water that has a salinity level between that of freshwater and seawater. It is a mix of freshwater and saltwater, typically found in estuaries, coastal aquifers, and certain underground sources. Utilizing brackish water as an alternative water source for various purposes, including concrete production, can help alleviate the strain on freshwater resources while offering a more sustainable approach to water use. Concrete production is a water-intensive process, with significant water consumption throughout its lifecycle. Miller et al. (2018) reported the concrete industry as responsible for 9% of global industrial water withdrawals in 2012, which is approximately 1.7% of the total global water withdrawal. They also predicted that by 2050, 75% of the water demand for concrete production is expected to occur in regions known for low water resources. This substantial water usage highlights the importance of addressing water-related challenges in the concrete sector (Miller et al. 2018).

Miller et al (2018) clearly proved the need for alternative water sources to alleviate the strain on freshwater resources in concrete production. Despite the scarcity research seeking solutions for implementing new sources of alternative water, a movement has begun in recent years to meet the challenge of freshwater alternatives for making concrete. A study conducted by Dasar et al. (2020) indicates that seawater can potentially reduce reliance on freshwater supplies and contribute to sustainable concrete manufacturing practices.

Heimdal founders Erik Millar and Marcus Limato started figuring out how to pull CO_2 out of the ocean when they were working on their MS degrees at Oxford. They are implementing their discovery through their company and using renewable energy and electricity to produce carbon-negative industrial materials, including limestone for making concrete. They are still in the laboratory phase of the development, but their results are promising (Coldewey, 2021).

By examining the feasibility and impact of using ocean and sea water in this study, we aim to contribute to the growing body of knowledge on sustainable water use practices in the concrete industry. If successful, the utilization of ocean and sea water as a viable water source for concrete holds significant promise. This approach could alleviate the burden placed on freshwater resources, mitigate the need for extensive freshwater transportation infrastructure, and contribute to sustainable water management practices. Furthermore, by tapping into unconventional water sources, such as brackish water and wastewater treatment plant effluent, the construction industry could reduce its reliance on freshwater supplies and potentially alleviate the strain on freshwater reserves.

The innovative aspect of this research lies in the simultaneous consideration of salinity levels and the effects of acidity/alkalinity on the compressive strength of Portland concrete. By comprehensively examining the interplay between these factors, the study aims to identify the optimal boundaries for salinity and the pH that ensures the desired compressive strength of concrete. This investigation holds immense potential for expanding the range of water sources used in concrete production, thereby paving the way for the adoption of alternative water sources in construction projects worldwide.

In addition to addressing the scarcity of freshwater resources on a global scale, this study tackles the economic costs associated with accessing drinking water. By establishing the minimum acceptable standard of compressive strength in concrete samples under various water conditions, including alkaline and acidic environments, the research seeks to provide practical guidelines for utilizing different water sources. Ultimately, this endeavor aligns with the United Nations' sustainable development goals, specifically those aimed at substantially increasing water-use efficiency and addressing water scarcity by 2030. The 2021 report gave a global scale increase in water efficiency since 2015. By 2018, the report noted “an increase of 15 percent in the industrial sector and 8 percent in both the services and agriculture sectors.” (FAO and UN Water, 2021, p. 23) The report covered 166 countries.

The significance of this research is underscored by the staggering statistics surrounding water stress illustrated in Figure 1-1. Presently, an estimated 2.3 billion individuals reside in water-stressed countries, with 733 million people experiencing high or critically water-stressed conditions (FAO and UN-Water, 2021). By expanding our understanding of the optimal use of water in concrete production, this study endeavors to contribute to global efforts in overcoming water scarcity and achieving sustainable water management practices.

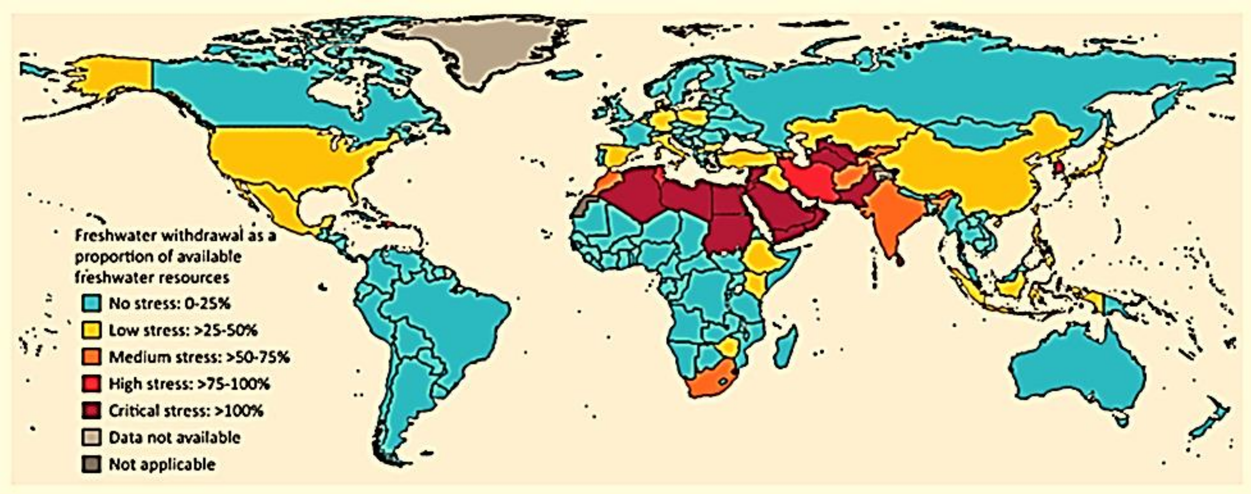


Figure 1-1 Global Levels of Water Stress (UN, 2021, p. 14)

1.3 Objectives

1.3 .1 The Primary Objectives

This research study achieves the following objectives:

- Investigate the feasibility of using eight different water qualities, including unconventional water sources, as substitutes for drinking water in concrete production, with a specific focus on their application in the construction industry.
- Evaluate the relationships between the water-to-cement ratio, total dissolved solids (TDS), and pH levels in concrete, and understand how variations in these water quality parameters impact compressive strength.
- Address the dual objective of saving freshwater resources and reducing construction costs by identifying suitable boundaries for water quality parameters and establishing

guidelines for the utilization of different water sources. This research aims to enable the construction industry to adopt unconventional waters, such as brackish water or wastewater treatment plant effluent, thereby promoting water conservation efforts and providing a more sustainable and economically viable approach to concrete production.

By achieving these objectives, this research study seeks to advance our understanding of water quality considerations in concrete production, promote sustainable water management practices in the construction industry, and contribute to the broader goal of conserving freshwater resources while reducing construction costs.

1.3 .2 The Specific Objectives

- To investigate the production of concrete using different water qualities based on laboratory studies. This objective involved conducting comprehensive laboratory experiments to assess the effects of utilizing various water sources on the properties and performance of concrete.
- To quantify and compare the compressive strength of concrete specimens produced using eight different water qualities in comparison to conventional concrete. This objective involved conducting laboratory tests to evaluate the performance of concrete produced with various water sources, while providing insights into the effectiveness and suitability of using alternative water qualities in concrete production.
- To analyze the impact of water quality parameters, including total dissolved solids (TDS) and pH levels, on the properties of concrete. This objective aims to investigate the relationship between water quality and concrete performance, particularly in terms

of compressive strength, to understand how variations in water quality parameters influence the overall quality and durability of concrete.

- To explore the feasibility of utilizing unconventional water sources, such as brackish water or wastewater treatment plant effluent, as substitutes for freshwater in concrete production. This objective focused on contributing to sustainable water management practices in the construction industry by assessing the viability and potential benefits of using alternative water sources in concrete manufacturing processes.

By accomplishing the above objectives, this research shed light on the importance of considering specific water qualities in practical applications, particularly within the construction industry. This study also contributes to both the concrete research community's and concrete industry's body of knowledge by providing experimental evidence regarding the production and compressive strength of concrete using diverse water quality sources.

1.4 Scope of Work

The scope of this dissertation is limited to Table 1-1:

1. pH in water used in this study is in the range of (6-8).
2. TDS content for different experiments ranged from 500-1,000, 1001-2,000, 2001-3,000, and 3001-4,000.
3. The water-to-cement ratio is in the range of (0.4-0.6).
4. Cement type for this study: Type II.

Table 1-1. This Dissertation Scope

TDS	*(500-1,000)*	*(1001-2,000)*	*(2001-3,000)*	*(3001-4,000)*	*Potable*
pH	6	6	6	6	Potable
pH	8	8	8	8	Potable

Included	**Excluded**
Industrial favored water	Saline water
Optimal drinking water & permitted to drink water	Sea water
Brackish water	Brine

1.5 Methodology

The methodology section of this dissertation outlines the approach and procedures used to conduct the research and achieve objectives. It provides a clear roadmap of the steps taken to investigate the identified problem, analyze data, and draw conclusions. The following outline represents the methodology used in this dissertation presented as steps to be followed:

1.5.1 Problem Statement

The core challenge addressed by this research is determining the optimal parameters for water quality in concrete production to ensure robust compressive strength outcomes. Specifically, the study investigates the interplay between pH and Total Dissolved Solids (TDS) concentrations, identifying that a pH level of 6 and a TDS value of 2,000 constitute the ideal boundary range for achieving superior results.

1.5.2 Objectives of Work Scope

Define the specific objectives of the research and establish a scope of work. Make sure the objectives are clear, measurable, achievable, relevant, and time-bound. These objectives include:

- Comprehensive Literature Review:

  Conduct a thorough review of existing literature related to TDS and pH boundary ranges, water-to-cement ratio, and their effects on concrete properties. Summarize the key findings and identify any gaps in the concrete production of water knowledge and research plan.

- Identify Potential Causes of Variations in Concrete Properties:

  Identify the potential causes for variations in concrete properties based on the TDS and pH boundaries range. Consider factors such as aggregate quality, cement type, mixing process, curing conditions, and environmental factors.

- Evaluate and Confirm Causes:

  Analyze the identified potential causes through experimentation and testing. Evaluate their impact on concrete properties and confirm their significance in relation to the TDS and pH boundaries range.

- Identify Potential Solutions:

  Based on confirmed causes, propose potential solutions to optimize concrete properties. Consider modifications in the water-to-cement ratio, aggregate selection, cement type, mixing techniques, and curing methods.

- Evaluate and Select Solutions:

Conduct further experimentation and testing to evaluate the effectiveness of the potential solutions. Compare the results with the desired concrete properties and select the most suitable solutions.

- Implement and Confirm Solutions:

  Implement the selected solutions in the concrete mix design and manufacturing process. Monitor and confirm their effectiveness by testing concrete samples.

- Standardize, Monitor & Control Process:

  Develop standardized procedures for concrete mixing, curing, and testing. Implement a robust monitoring and control system to ensure consistency in the process and evaluate the adherence to the TDS and pH boundaries range.

- Conduct Ongoing Data Analysis:

  Collect data from concrete tests and analyze the results using statistical techniques. Evaluate the influence of the TDS and pH boundary range on concrete properties also assess the effectiveness of the implemented solutions.

- Compare and Analyze Results:

  Analyze the comparison results to determine the relationship between TDS and pH boundaries range as well as the water-to-cement ratio.

- Submit Report and Conclusions

  Summarize the findings of this research, including impact of TDS and pH boundaries on concrete properties and the effectiveness of the implemented solutions. Provide recommendations for future research and practical applications.

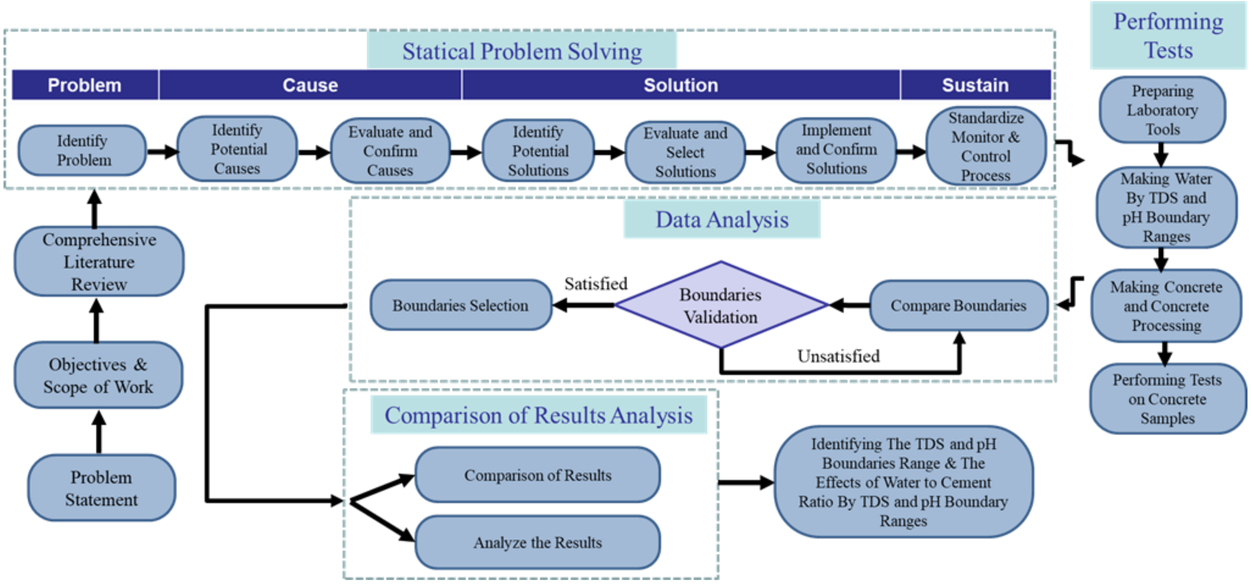


Figure 1-2 Research Methodology Flow Chart

Figure 1-2 begins with the Problem Statement in the lower left corner and then goes up, across, and onward to the Performing Tests which lead to the Data Analysis, followed by a Comparison of Results Analysis. The final step is identifying the effects of the water-to-cement ratio based on the water pH and total dissolved solids (TDS).

1.6 Hypotheses

The hypotheses of this study are:

- Water with a higher percentage of solutes than freshwater (1500 mg / l) can be used in making concrete.
- The pH of brackish water used in concrete production has a positive effect on concrete compressive strength.

1.7 Chapter 1 Summary

In the first chapter of this dissertation, a concise overview was provided, covering the general aspects of our research covering different types of water that can replace freshwater in concrete production. These general aspects encompassed several key components, including the introduction, importance, and the necessity of the research topic, as well as our research objectives. The chapter focused on setting the context for the research by providing background information on the topic and establishing its relevance. It highlighted the significance of investigating the impact of water quality on concrete production, emphasizing the need for further exploration and a greater understanding of the importance of utilizing previously unacceptable water in concrete production. By presenting the research problem and its significance, the chapter presented a clear understanding of the role water plays in concrete construction.

The general aspects of the research in the first chapter served as a foundation for the entire dissertation, presenting the overarching context and objectives of the study. They provided a framework for the subsequent chapters by outlining the research problem, highlighting its importance, and specifying the goals and objectives. The chapter aimed to engage the reader, establish the significance of the research, and demonstrate the need for further investigation. By setting the context and defining the research objectives, it laid the groundwork for the subsequent chapters, which would delve deeper into the theoretical concepts, methodology, experimental findings, and conclusions of the study. Overall, the general aspects of the research in the first chapter aimed to create a comprehensive and cohesive introduction to this dissertation, guiding the reader towards a deeper understanding of the research topic and its significance.

Chapter 2 Literature Review

2.1 Introduction

This chapter provides a comprehensive analysis of relevant literature and previous studies pertaining to seawater usage in concrete production and processing. The chapter also introduces concrete and its constituent materials, along with an exploration of the technological aspects of concrete production using seawater as a theoretical foundation for this research. By synthesizing these elements, this chapter enhances our understanding of the critical role water plays in concrete applications.

Water is undeniably essential to several industries who use it in production. However, the salts and minerals in water can also limit production (Neville & Brooks, 2010, Ch. 3; Kosmatka et al., 2002, Ch. 4). Unsuitable water in concrete construction negatively affects cement and concrete compatibility, decreases strength, and causes rebar corrosion (ACI Committee 201, 2010, Section 4.2; Malhotra & Carino, 2004, Chapter 2). Researchers have endeavored to reduce and eliminate these limitations through various approaches. In most concrete mixtures, suitable water is considered potable water, which meets drinking water standards (Mindess et al., 2003).

2.2 Exploring Theoretical Foundations

2.2.1 Water Situation in USA and Worldwide

Water scarcity is a pressing global concern that has far-reaching implications for various sectors, including the construction industry. As water resources become increasingly limited, it is crucial to recognize the significance of conserving freshwater in construction practices. This paper examines the water situation in the USA and worldwide, highlighting the importance of water conservation in the construction industry.

2.2.1.1 Water Situation in USA:

- Water Scarcity:

  The United States is one of the countries facing water stress due to population growth, climate change, and increasing water demand (United Nations, 2021). Statistics reveal that approximately 40 out of 50 U.S. states anticipate water shortages within the next decade (American Rivers, 2021). These alarming figures emphasize the urgent need for water conservation measures in all sectors, including construction.

- Water Consumption in the Construction Industry:

  Concrete production alone accounts for approximately 8-10% of global water consumption (United Nations, 2021). Concrete requires a significant amount of water for mixing and curing. The water-to-cement ratio plays a crucial role in achieving the desired workability and strength of concrete mixtures. Typically, the water-to-cement ratio ranges from 0.4 to 0.6, meaning that for every kilogram of cement used, 0.4 to 0.6 kilograms (or 4.23 to 6.34 quarts) of water are required. Considering the massive scale of concrete usage in construction projects worldwide, the water consumption in concrete structures is a huge concern. Addressing the water consumption in concrete structures is vital to sustainable development and efficient water management in the construction industry. Implementing water-saving strategies, such as using alternative water sources, adopting water-reducing admixtures, and optimizing the water-to-cement ratio, can conserve freshwater resources and reduce the environmental impact of concrete production. The construction industry can play a crucial role in promoting sustainable water use both nationally and globally by implementing water-saving measures. It is estimated that construction activities account for approximately 13% of global water consumption (United Nations, 2021). Mixing concrete, dust suppression, and equipment cleaning contribute to water usage; thus, implementing water-saving strategies is crucial to sustainable development.

2.2.1.2 Water Situation Worldwide:

- Global Water Scarcity: Water scarcity is a global issue that affects multiple regions. According to the World Health Organization (WHO, 2022), over two billion people live in water stressed countries, and water supplies are expected to diminish to an even greater extent due to climate change and overpopulation. Furthermore, the United Nations predicts that by 2050, nearly half of the world's population will reside in areas facing water stress (United Nations, 2021). These statistics emphasize the need for global efforts to conserve freshwater resources.
- Water Use in Industrial Sectors: Industries, including construction, play a significant role in global water consumption. The construction sector is responsible for significant water use throughout each project life cycle. This water is needed for material extraction, manufacturing, and on-site operations. Efficient water management practices, such as wastewater recycling and rainwater harvesting, can significantly reduce the industry's water footprint. (UN Water, 2018). Moreover, The Water Footprint Network (2019) estimates that for every cubic meter of concrete,

approximately 200 to 300 liters of water are used. This statistic focuses on the substantial water demand directly related to concrete production processes.

2.2.1.3 Conserving Freshwater in Construction

- Environmental Impact: By reducing freshwater consumption, construction activities can help preserve natural ecosystems and maintain the ecological balance. The UN Environment Programme (20107) emphasized the importance of construction entities globally reducing freshwater resources to protect the ecosystems (United Nations Environment Programme, 2016). The World Green Building Council (2017) further emphasized the importance of construction sectors reducing their water use to preserve "aquatic habits and biodiversity." According to the United Nations Environment Programme (UNEP, 2016), the construction sector accounts for approximately 10% of global freshwater withdrawals. The World Green Building Council (2017) estimates that by implementing water-efficient practices in construction, water consumption can be reduced by up to 50%. The Water Footprint Network found that water use in the construction of a typical residential building can range from 500 to 2,500 cubic meters (i.e., 500,000 to 2,500,000 liters or 132,086 to 660,430 gallons) depending on the building size and construction methods. By adopting sustainable water management strategies, such as using alternative water sources and implementing water-efficient technologies, the construction industry could save millions of gallons of water annually, which would have a tremendous impact on preserving freshwater resources and protecting aquatic habitats and biodiversity.

2.2.1.4 Economic Benefits:

In addition to its environmental advantages, water conservation in the construction industry brings significant economic benefits. By adopting water-efficient practices, construction companies can reduce operational expenses and enhance their competitiveness. The potential financial risks associated with water scarcity, including increased water prices and operational disruptions, can be mitigated through the implementation of water-efficient technologies and strategies (World Business Council for Sustainable Development, 2014). By reducing water consumption and optimizing resource management, construction firms can achieve cost savings and improve their long-term economic resilience (International Finance Corporation, 2020).

2.3 Sustainable Development:

Conserving freshwater resources in the construction sector is in line with the principles of sustainable development. It ensures the availability of water resources for future generations and contributes to the achievement of global sustainability goals. By promoting the efficient use of water and adopting sustainable practices, the construction industry can support long-term societal and environmental benefits. Water conservation in construction plays a crucial role in achieving sustainable development goals, such as ensuring water availability, protecting ecosystems, and addressing the challenges of water scarcity (United Nations, 2015).By prioritizing water-saving measures and adopting sustainable practices, the construction sector can actively contribute to mitigating water scarcity and promoting a more sustainable future.

2.3.1 Concrete

According to established literature and industry standards, concrete is a composite material composed of different components in specific proportions. These components include cement, aggregates (such as sand and gravel), water, and often supplementary cementitious materials (SCMs) or admixtures. The percentage of each component in concrete varies depending on concrete's desired properties and application. The Neville (2011) pie chart shows cement with 7-15% of the total concrete volume; with aggregates between 60 and 75%, providing bulk and strength to the concrete, and water ranging from 14–25% by weight. hydration provided by water is the key to the workability of the mixture. Additionally, SCMs, such as fly ash or silica fume, can serve as partial replacements for cement, often ranging from 10–25% by weight, to improve specific properties of the concrete as shown in Figure 2-1.

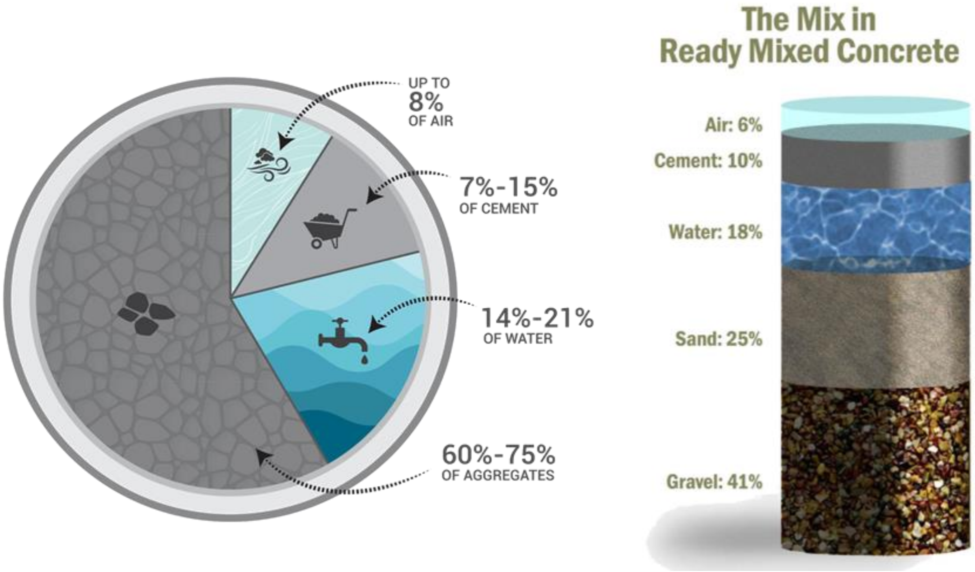


Figure 2-1 A pie chart showing main components concrete. (a) a pie chart showing air, cement, water, and aggregate percentages in concrete from Tokyo Cement and (b) a layered look at air, cement, water, sand, and gravel percentages normally found in ready-mixed concrete from Chaney Enterprises.

Mehta and Monteiro (2013) emphasize the importance of the water-to-cement ratio (W/C ratio) in concrete mix design. This ratio plays a critical role in determining the strength, durability, and workability of concrete. The optimal W/C ratio varies depending on factors such as the desired strength and exposure conditions.

These findings emphasize the importance of properly proportioning concrete components to achieve the desired performance characteristics. By adjusting the percentages of cement, aggregates, water, and supplementary materials, engineers and researchers can tailor the properties of concrete to meet specific project requirements.

2.3.1.1 Types of Water

Water exists in different forms and can be categorized into various types based on its chemical properties. The three main types of water are neutral water, acidic water, and alkaline water.

- Neutral Water

Neutral water is defined as water with a pH of 7. It has no inherent reactivity, meaning that if a small amount of alkaline substance is added to neutral water, the environment quickly becomes alkaline. Similarly, if a small amount of acid is added to neutral water, the environment immediately becomes acidic. Therefore, neutral water is considered to be a passive medium and does not contribute significantly to concrete improvement. From a scientific perspective, neutral water is considered to be dead water (Yavari, 2006).

- Acidic Water

Acidic water has a pH between 0 and 7. Over 2 billion people live in water-stressed countries, which is expected to be exacerbated in some regions as result of climate change and population growth (WHO 2022). Drinking acidic water in the long term can lead to diseases such as osteoporosis (Miller, 1977) and arthritis (Arthritis Foundation, 2023).

- Alkaline Water

Alkaline water is defined as water with a pH between 7 and 14, capable of neutralizing and alkalizing acidic environments. Palladino and Goldman (2023) say that most alkaline water has a pH of 8 or 9, and their studies led them to the conclusion that it is safe. Wright (2015) whose focus is on dental health asserts that both natural and ionized alkaline water can help protect teeth from decay with a pH of 5.5 or 6.7. Drinking water should have a pH between 6 and 8.5. (Yehia and Said, 2021).

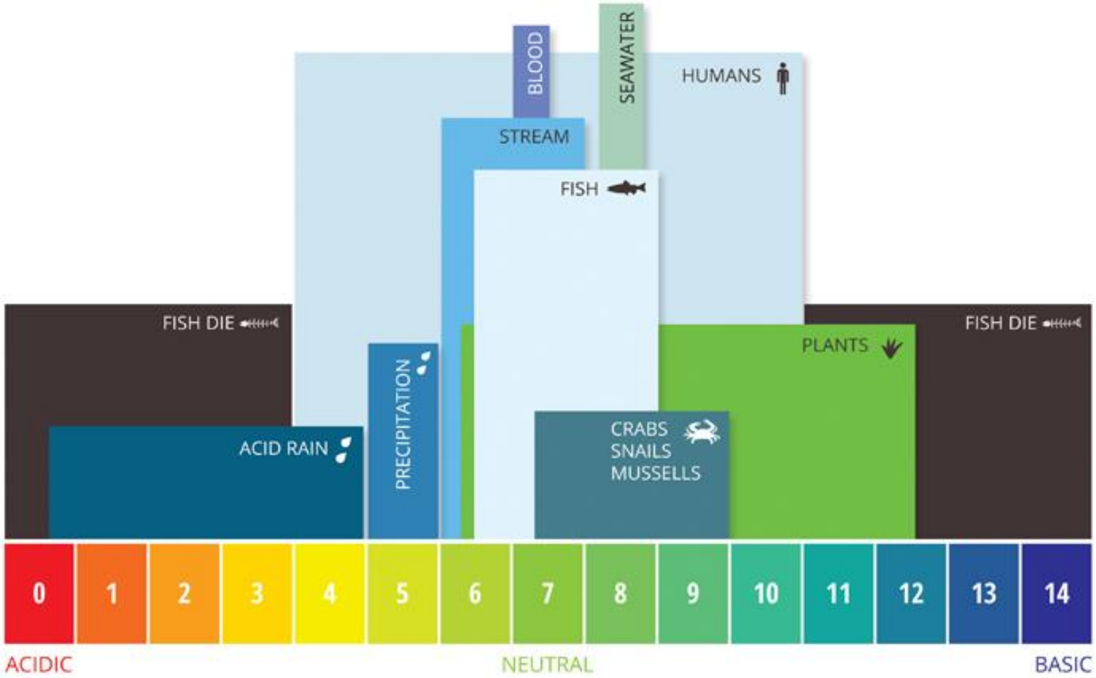


Figure 2-2. pH levels in the Coosa River monitor the river's aquatic flora, crabs, and fish, which require a narrow pH range from 6.0 to 9.0. to thrive. (Source: Coosa River Inc., Laurel AL) Riverhttps://coosariver.org/waterqualityparameterspart1/)

The pH level of different organisms and solutions can be measured in both oceans and freshwater. Fig. 2-2 shows its effect in a river environment. (Glenn, 2023; Chang and Overby, 2017).

The pH level of water plays a crucial role in the aquatic ecosystem and has significant implications for both aquatic organisms and human health. In the context of this dissertation, understanding the importance of pH is essential for evaluating the impact of water quality on concrete production. Aquatic organisms have specific pH requirements for their survival and well-being. Most aquatic creatures thrive within a pH range of 6.5 to 9.0, although some species can tolerate pH levels outside of this range as seen in Figure 2-2. Deviations from the optimum pH range can stress or even cause mortality in organisms, reducing hatching and survival rates. Extreme pH values can also increase the solubility of chemicals and heavy metals in water, making them more toxic and increasing the risk of absorption by aquatic life. While humans have a higher pH tolerance, there are still concerns related to pH levels. pH values exceeding 11 or falling below 4 can cause skin and eye irritations, and a pH below 2.5 can cause irreversible damage to skin and organ linings. Elevated pH levels can increase the mobility of toxic metals, posing health risks both aquatic life and humans. pH levels outside of the 6.5 to 9.5 range can also damage pipelines and other systems, leading to increased heavy metal toxicity. Furthermore, even minor changes in pH can have long-term effects on aquatic ecosystems. A slight increase in pH can enhance the solubility of nutrients like phosphorus, promoting excessive plant growth. This, in turn, can lead to eutrophication, where nutrient-rich waters become depleted of dissolved oxygen, causing stress to other organisms in the ecosystem.

In summary, understanding the importance of pH in water is vital for assessing the impact of water quality on concrete production. By investigating the relationship between pH levels and concrete properties, this research aims to contribute to the optimization of water quality parameters in concrete production processes, ensuring both environmental sustainability and the production of high-quality concrete.

Water can be classified into several types based on its total dissolved solids (TDS) content, which refers to the concentration of dissolved substances in water. The TDS value represents the sum of inorganic salts, minerals, and other dissolved solids present in water. The main types of water based on TDS levels include low, moderate, and high levels of TDS in water. The classification of water based on TDS levels is widely recognized and utilized in various research studies and publications. While I cannot provide real-time citations, here are some common sources that discuss the classification of water based on TDS:

- World Health Organization (WHO): The WHO provides guidelines and standards for drinking water quality and references TDS classification in its publications related to water quality assessment.
- Environmental Protection Agency (EPA): The U.S. EPA includes TDS as one of the parameters for assessing water quality and provides guidance on TDS levels in different water sources.
- Water treatment and filtration industry publications: Journals, reports, and publications related to water treatment and filtration often discuss TDS classification as a basis for selecting appropriate treatment methods.

- Low TDS

Low TDS in water typically has a TDS value below 500 parts per million (ppm). It is often associated with distilled water or water that has undergone advanced filtration processes. Low TDS water is characterized by its purity and lack of significant mineral content (Johnson and Smith, 2019).

- Moderate TDS

Moderate TDS water generally falls within the range of 500-1,000 ppm. It usually contains a balanced concentration of minerals and salts. This type of water is commonly found in natural sources such as springs and wells (Johnson and Smith, 2019).

- High TDS

High TDS water has a TDS value above 1,000 ppm. It is typically enriched with minerals and salts due to its contact with geological formations or underground sources. High TDS water is often found in certain regions with specific geological characteristics (Johnson and Smith, 2019).

Water can be classified into other types based on its TDS content. The three primary types of water are based on TDS levels and are described below:

Freshwater exhibits low salinity levels and is commonly found in lakes, rivers, and underground aquifers. When the TDS value is below 1,000 parts per million (ppm), the bodies of water that meet this criteria can provide safe drinking water, responsible irrigation, and careful management of the water needed by industries.

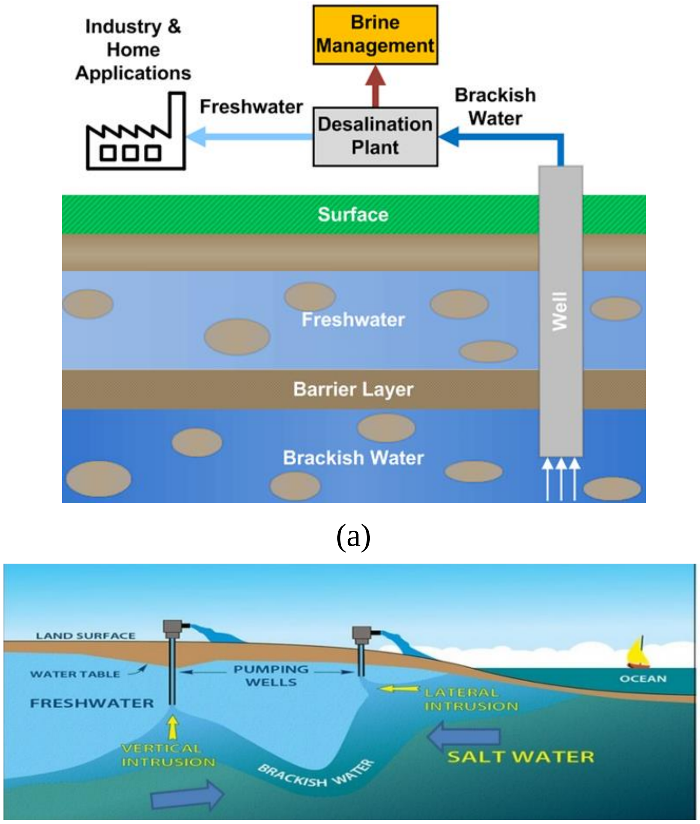
Brackish water falls between freshwater and saline water in terms of salinity (Table 2-1). It typically possesses a TDS value ranging from 1,000 to 10,000 ppm. Brackish water is frequently encountered in estuaries, coastal areas, and specific inland regions. For specific applications, such as drinking or agriculture, desalination or treatment may be required (United Nations Environment Programme, 2016).

Saline water has high salinity levels as shown in Table 2-1. It is primarily found in oceans and seas, featuring a TDS value greater than 10,000 ppm. Due to its elevated salinity, saline water is generally unsuitable for direct human consumption or for use in most agricultural practices without desalination or specialized treatment (Millero, 2013). Table 2-1 shows brackish water as having a higher TDS content compared to freshwater but a lower TDS than seawater.

Table 2-1 Types of Water Based on TDS Levels (Freeze and Cherry, 1979)

Class name	Class Limits (Total dissolved solids range)
Fresh water	0 –1,000 mg/L
Brackish water	1,000 –10,000 mg/L
Saline water	10,000 – 100,000 mg/L
Brine	> 100,000 mg/L

Brackish water contains various prominent dissolved solids such as sodium chloride, manganese, iron, sodium sulfate/bicarbonate, calcium sulfate/bicarbonate, and sometimes naturally occurring radioactive material like radium (U.S. Geological Survey, 2011). The composition of brackish water can vary significantly and may even change over time. In recent years, brackish groundwater has gained attention as an alternative to freshwater, particularly in regions where freshwater availability is limited. Extraction of brackish water is often conducted from suitable locations, typically below freshwater aquifers. To make brackish water suitable for various purposes, desalination techniques are employed to lower its salinity and TDS content. Advanced membrane treatment technologies such as reverse osmosis (RO) and ultrafiltration (UF) are commonly utilized for this purpose (Water Research Foundation, 2018). However, it is important to note that because many brackish water resources are located inland, careful consideration of brine minimization and management is essential for the successful operation of desalination plants (American Water Works Association & Water Environment Federation, 2017).



(a)

(b)

Figure 2-3 Bracket Water: (a) brackish water processing and (b) its relationship to fresh water and salt water. Brackish water is water that is saltier than fresh water but not as salty as sea water. Source:https://www.saltworkstech.com/applications/brackish-water-desalination.

By utilizing brackish water as an alternative water source for concrete production, it is possible to reduce reliance on freshwater and conserve this valuable resource, as shown in

Figure 2-3 (a). Desalination technologies, such as reverse osmosis and ultrafiltration, can effectively lower the salinity and TDS levels of brackish water, making it suitable for use in the concrete production processes. This approach supports sustainable water management practices and contributes to the development of environmentally sustainable construction practices (Ahdab and Lienhard, 2021).

2.3.1.2 Water Properties

Water exhibits various physical and chemical properties that distinguish it from other natural substances. These properties are described below.

Physical Properties of Water

- Suspensions: Suspended solids can exist in water in either organic or inorganic forms. Inorganic suspended solids, such as clay, silt, and other soil components, are naturally found in surface waters. Organic suspended solids, such as plant matter and biological particles, are considered natural contaminants in surface waters (Benjamin, 2015)
- Turbidity: Turbidity is a measure of light absorption or scattering by suspended particles in water (Benjamin, 2015).
- Color: Drinking water should ideally be colorless at shallow depths and slightly bluish at greater depths. If significant dissolved or suspended materials are present in the water, this water may exhibit color. The color can be either inherent or apparent. Inherent color refers to the color caused by dissolved substances that remain after removing suspended materials, while apparent color refers to the color caused by suspended solids (Benjamin, 2015).

- Taste and Odor: Drinking water should be odorless. Odor in water is typically associated with organic substances like ammonia (Multipure, 2022), while taste is primarily influenced by mineral content. Substances that create an odor in water usually impart a taste as well, although the reverse is not always true (American Water Works Association & Water Environment Federation., 2017).
- Temperature: Temperature is not a direct parameter for evaluating drinking water quality. However, it is a crucial factor in natural water systems. Temperature affects many chemical reactions that occur in aquatic systems and has a noticeable effect on gas solubility in water (American Water Works Association & Water Environment Federation., 2017).

Chemical Properties of Water

- Dissolved Solids: Dissolved solids refer to solid materials that remain as solid deposits after filtration and evaporation processes. Dissolved solids can be of organic or inorganic nature (Benjamin, 2015).
- Alkalinity: Alkalinity refers to the ability of water to neutralize hydrogen ions and participate in acid-base reactions. It is determined by the presence of alkaline substances in water (U.S. Geological Survey, 2018)
- Hardness: Hardness is a measure of the concentration of metal cations in a solution, usually caused by dissolved minerals (American Water Works Association, & Water Environment Federation., 2017).

The pH of natural waters is generally in the range of pH 6 to 8. The pH of natural water is generally in the range of 6 to 8 (American Water Works Association, 2011).

2.4 Types of Portland Cement

Portland Cement is classified into five main types (Table 2-2) and are defined as:

- Type I Portland Cement (ordinary cement): This type of cement is the most widely used type in Iran and around the world. It exhibits high quality and is suitable for regions with moderate and dry climates. Type I cement is commonly used in general construction, flooring, reinforced concrete structures, mortar, and plasters where there is no risk of sulfate attack (ACI Committee E-701 2013).
- Type II Portland Cement (moderate heat cement or modified heat): This type of cement has increased resistance against sulfate-bearing soils and saline soils. It produces lower heat during chemical reactions compared to Type I cement. Type II cement has a slower setting time, which can help prevent temperatures from rising at concrete work sites in hot weather. It is used in the construction of foundations, bridge abutments, and barrier walls, which are generally in areas where concrete is exposed to sunlight (ACI Committee E-701, 2013).
- Type III Portland Cement (rapid hardening cement): Type III cement develops high strength within a short period (typically one week or less). It is known for its early strength development and is often used when formwork needs to be removed quickly. The 3-day strength of Type III cement is nearly equivalent to the 7-day strength of Type I cement. It is often applied in emergency repairs or when laying concrete in cold weather conditions. However, it should not be used in massive or large concrete elements due to the significant heat generation during hydration (ACI Committee E-701, 2013).

- Type IV Portland Cement (Low Heat Cement or Slow Setting Cement): Type IV cement, also known as a slow setting cement that produces even lower heat compared to Type II cement. It is suitable for massive concreting projects, especially in seasons with high temperatures (above 40 to 50 degrees Celsius). It is commonly used for building long walls and multi-layered concrete structures (ACI Committee E-701, 2013).
- Type V Portland Cement (sulphate resistant cement): Type V cement has a slower setting time and lower heat generation compared to Type I cement. It is specifically designed for concrete exposed to severe sulfate attack. However, in the coastal areas of the Persian Gulf where chloride contamination is also present, Type II cement should be used instead. In regions like Abadan and neighboring cities, Type V cement is preferred due to its good resistance to sulfates. However, when Type V cement is scarce in the market, Type II cement becomes the best alternative (ACI Committee E-701, 2013).

In the United States, different standards are applicable based on the category of cement.

Table 2-2 Five Types of Portland Cement

Cement Type	Description
Type I	Normal cement
Type II	Moderate sulfate resistance
Type II (MH)	Moderate heat of hydration and sulfate resistance
Type III	High early strength
Type IV	Low heat hydration
Type V	High sulfate resistance

2.4.1. ASTM Standards for Portland Cement

The five types of Portland cement based on ASTM C150/C150M-22 (ASTM 2022) are described in Table 2-2.

Blended hydraulic cements, as specified by ASTM C595/C595M-2021 (ASTM 2021), use the following nomenclature as shown in Table 2-3. Blended hydraulic cements have special performance properties. They undergo additional testing and are designated by letters in parentheses based on their cement type as shown in Table 2-3.

Table 2-3 Portland Blended Hydraulic Cement Types

Cement Type	Description
Type IL	Portland-limestone cement
Type IS	Portland-slag cement
Type IP	Portland-pozzolan cement
Type IT	Ternary blended cement

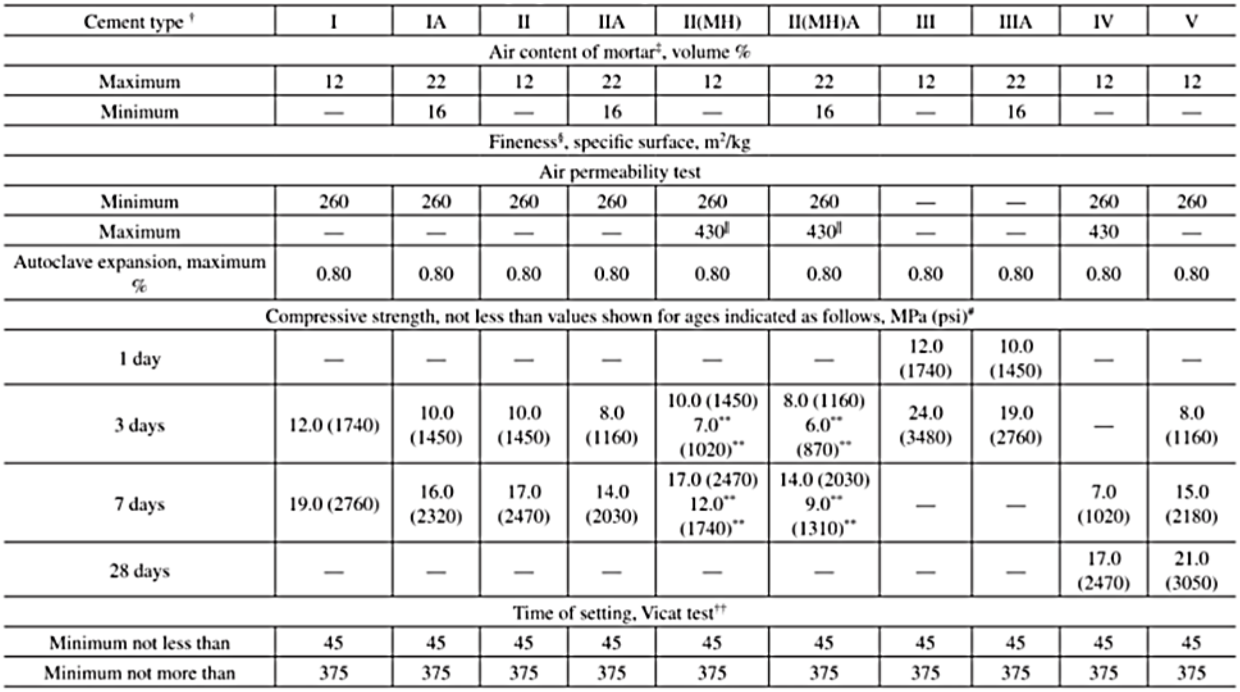
For example, Type IP(MS) refers to Portland-pozzolan cement with moderate sulfate resistance. ASTM C1157/C1157M-20a (ASTM, 2020) describes hydraulic cementt based on their performance attributes shown in Table 2-4.

Table 2-4 Hydraulic Cement 2-Letter IDs Describing its Functions

Cement Type	Description
Type GU	General use
Type HE	High early strength
Type MS	Moderate sulfate resistance
Type HS	High sulfate resistance
Type MH	Moderate heat of hydration
Type LH	Low heat of hydration

Table 2-5 of ASTM C150/C150M-22 (ASTM 2022) is the Standard Specification for Portland Cement. It outlines the physical requirements for Portland cement, and one of the key parameters is compressive strength. Compressive strength is a vital property of cement that indicates its ability to withstand applied loads and provide structural integrity to concrete. This standard specifies the minimum compressive strength that the cement must achieve after specified curing periods.

Table 2-5 ASTM C150/C150M-22 standard on physical requirements

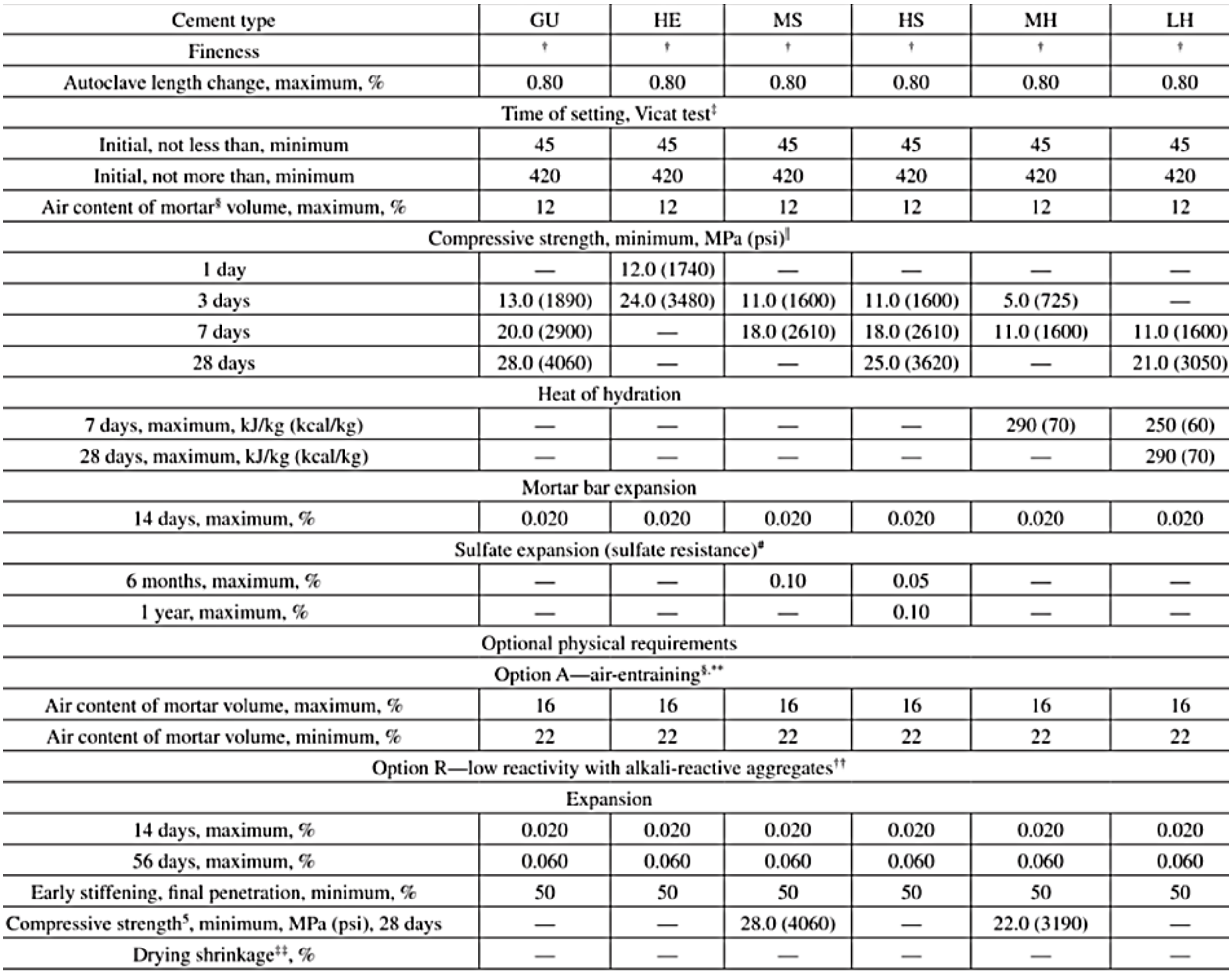


Cement type [†]	I	IA	II	IIA	II(MH)	II(MH)A	III	IIIA	IV	V
Air content of mortar[‡], volume %										
Maximum	12	22	12	22	12	22	12	22	12	12
Minimum	—	16	—	16	—	16	—	16	—	—
Fineness[§], specific surface, m²/kg										
Air permeability test										
Minimum	260	260	260	260	260	260	—	—	260	260
Maximum	—	—	—	—	430[‖]	430[‖]	—	—	430	—
Autoclave expansion, maximum %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Compressive strength, not less than values shown for ages indicated as follows, MPa (psi)[#]										
1 day	—	—	—	—	—	—	12.0 (1740)	10.0 (1450)	—	—
3 days	12.0 (1740)	10.0 (1450)	10.0 (1450)	8.0 (1160)	10.0 (1450) 7.0[**] (1020)[**]	8.0 (1160) 6.0[**] (870)[**]	24.0 (3480)	19.0 (2760)	—	8.0 (1160)
7 days	19.0 (2760)	16.0 (2320)	17.0 (2470)	14.0 (2030)	17.0 (2470) 12.0[**] (1740)[**]	14.0 (2030) 9.0[**] (1310)[**]	—	—	7.0 (1020)	15.0 (2180)
28 days	—	—	—	—	—	—	—	—	17.0 (2470)	21.0 (3050)
Time of setting, Vicat test[††]										
Minimum not less than	45	45	45	45	45	45	45	45	45	45
Minimum not more than	375	375	375	375	375	375	375	375	375	375

The acceptance of ASTM C150/C150M-22 (ASTM 2022) as by the concrete industry makes sure that Portland cement meets the necessary strength criteria for different structures and ensures a safer infrastructure. The specified compressive strength values provide guidance for engineers, contractors, and stakeholders to select the appropriate cement type for their specific project requirements. Meeting the compressive strength requirements is crucial as it directly impacts the overall performance and durability of concrete structures.

Table 2-6 also features a standard that establishes the physical requirements for hydraulic cement, specifically for general use and types (GU, MS, HS, and HE) shown below.

Table 2-6 ASTM C1157/C1157M-20a standard physical requirements attributes



Cement type	GU	HE	MS	HS	MH	LH
Fineness	†	†	†	†	†	†
Autoclave length change, maximum, %	0.80	0.80	0.80	0.80	0.80	0.80
Time of setting, Vicat test[‡]						
Initial, not less than, minimum	45	45	45	45	45	45
Initial, not more than, minimum	420	420	420	420	420	420
Air content of mortar[§] volume, maximum, %	12	12	12	12	12	12
Compressive strength, minimum, MPa (psi)[‖]						
1 day	—	12.0 (1740)	—	—	—	—
3 days	13.0 (1890)	24.0 (3480)	11.0 (1600)	11.0 (1600)	5.0 (725)	—
7 days	20.0 (2900)	—	18.0 (2610)	18.0 (2610)	11.0 (1600)	11.0 (1600)
28 days	28.0 (4060)	—	—	25.0 (3620)	—	21.0 (3050)
Heat of hydration						
7 days, maximum, kJ/kg (kcal/kg)	—	—	—	—	290 (70)	250 (60)
28 days, maximum, kJ/kg (kcal/kg)	—	—	—	—	—	290 (70)
Mortar bar expansion						
14 days, maximum, %	0.020	0.020	0.020	0.020	0.020	0.020
Sulfate expansion (sulfate resistance)[#]						
6 months, maximum, %	—	—	0.10	0.05	—	—
1 year, maximum, %	—	—	—	0.10	—	—
Optional physical requirements						
Option A—air-entraining[§,**]						
Air content of mortar volume, maximum, %	16	16	16	16	16	16
Air content of mortar volume, minimum, %	22	22	22	22	22	22
Option R—low reactivity with alkali-reactive aggregates[††]						
Expansion						
14 days, maximum, %	0.020	0.020	0.020	0.020	0.020	0.020
56 days, maximum, %	0.060	0.060	0.060	0.060	0.060	0.060
Early stiffening, final penetration, minimum, %	50	50	50	50	50	50
Compressive strength[5], minimum, MPa (psi), 28 days	—	—	28.0 (4060)	—	22.0 (3190)	—
Drying shrinkage[‡‡], %	—	—	—	—	—	—

These requirements encompass various attributes that contribute to the quality and performance of the cement. The standard covers parameters such as fineness, compressive strength, autoclave expansion, setting time, and chemical composition. These attributes ensure that the cement meets the necessary criteria for consistency, strength development, and durability. By adhering to the specifications outlined in ASTM C1157/C1157M-20a (ASTM, 2020), manufacturers can produce cement that is suitable for a wide range of applications and that meet the industries' quality standards.

2.4.1.1 Selection of Cement Type

The American Concrete Industry's Education Bulletin E3-13 Cementitious Materials for Concrete set forth guidelines to help its members and the industry select cement type based on the desired rate of strength development, susceptibility to chemical attacks, and thermal considerations (ACI Committee E-701, 2013). In cold weather conditions, it is necessary to use a cement that exhibits rapid heat generation during hydration. Conversely, in hot weather or when dealing with massive concrete placements, a cement with low heat generation is required. In the latter case, a lower water-to-cement ratio may be essential to ensure a satisfactory early-age strength (ACI Committee E-701, 2013). However, resistance to freezing and thawing does not significantly affect the choice of cement type.

2.4.1.2 Water-to-Cement Ratio

When determining the best water-to-cement ratio for achieving a desired average strength in concrete, it is beneficial to refer to relationships derived from experimental mixtures made with real construction materials. These mixtures simulate must actual conditions and materials used in construction projects. These experiments use various water-to-cement ratios to represent construction materials and help establish empirical relationships. These relationships provide insights into the effects of different water-to-cement ratios on the resulting strength of the concrete. Using these empirical relationships, engineers can estimate the water-to-cement ratio needed to achieve a specific target strength. This allows more accurate and efficient concrete mixtures, ensuring the desired strength and minimizing the use of excess water (ACI Committee E-701, 2013).

Notably, these relationships and empirical data are specific to the materials used in the experiments and should be applied with caution when working with different materials or in different conditions. Therefore, specific tests and evaluations should be conducted, using the representative materials selected for each construction project to determine the best water-to-cement ratio needed to achieve the desired strength.

2.4.1.3 Characteristics of Aggregates (Sand and Gravel) in Concrete

Aggregates used in concrete should be clean and free from clay, silt, dust or other impurities (Babu et al., 2014). They should also possess resistance against abrasion and stress. Siliceous aggregates, known for their hardness of 7 to 8, are considered the most durable aggregates used in concrete. However, limestone aggregates are commonly used with a hardness of 3 to 4 (Ineson 1990). Aggregates in concrete must also exhibit resistance to freezing and thawing. This resistance is influenced by factors such as aggregate porosity, permeability, and tensile strength. Higher aggregate porosity and permeability can result in decreased resistance to freezing and thawing, while higher tensile strength enhances resistance (Liu et al., 2018). Moreover, aggregates should demonstrate resistance to weathering. Notably, concrete made with angular aggregates tends to exhibit higher strength due to improved interlocking and friction between the aggregates. When aiming for high-strength concrete (above 350 to 400 Kg/cm^2), angular aggregates are recommended. However, for normal construction where lower strength is acceptable, rounded and irregular aggregates can be utilized.

2.5. Mechanical Properties of Concrete Aggregates

The first important property of concrete aggregates is their strength, which refers to the resistance of aggregates against fragmentation caused by impact loads. Aggregate strength can be determined by conducting tests on cylindrical specimens prepared from rock-like aggregates. The minimum height from which a standardized weight must fall onto the specimen to cause fragmentation is an indicator of the aggregate's strength. Moreover, strength, hardness or resistance to abrasion are all significant properties of aggregates used in roadways and heavily trafficked areas. Several tests exist to assess abrasion, which can occur due to the wearing caused by external friction or inter-particle friction.

In the abrasion test, a cylindrical specimen similar to the compressive strength test specimen is subjected to abrasion caused by rotating a metal disk against the compacted specimen. The abrasion value is expressed as the weight loss of the specimen in grams, relative to 20 minus one-third of the weight drop. A high-quality aggregate should have an abrasion value of less than 17, and an aggregate with an abrasion value lower than 14 is considered weak, according to the ACI Education Bulletin E3-13 guidelines (ACI Committee E-701, 2013).The friction test also evaluates aggregates in bulk form. In this test, particles of known weight are placed in a rotating cylinder that rotates at a speed of 30 to 33 revolutions per minute. The crushed material ratio is expressed as a percentage and represents the frictional characteristics of the aggregates. A friction test can be conducted on dry or moist aggregates, and variations in the test results indicate the effect of aggregate conditions based on their resistance to friction. Typically, a "friction value" of 7 to 8 is considered the maximum acceptable value. However, a drawback of this test is that it provides only small numerical differences between aggregates with a wide range of values.

Another commonly used American test that combines friction and abrasion is the Los Angeles (LA) abrasion test (ASTM C131/C131M-20) which is also employed in other countries (ASTM 2020). This test not only shows a good correlation with the actual abrasion of aggregates used in concrete but also with the compressive and flexural strengths of concrete made with specific aggregates. In this test, aggregates are selected according to specified particle sizes and then placed horizontally inside a cylindrical drum mounted on support bases. Steel balls are added to the drum, and the drum is rotated for a specified number of revolutions. The colliding and falling of aggregates and balls result in surface abrasion and friction, which are measured using the ASTM C131/C131M-20 method (ASTM 2020).

2.5.1 Strong and Weak Acids, Ionization Energy, and Periodic Table Trends

The ionization energy of an element affects the behavior of acids, including their strength and extent of ionization. Figure 2-4 shows how ionization energy increases due to an increase in nuclear charge (Glenn, 2023; Chang and Overby, 2017).

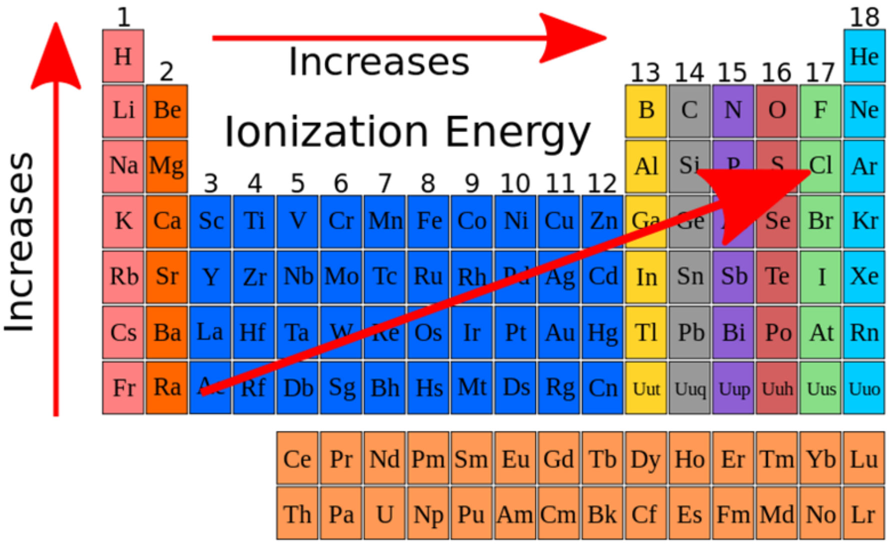


Fig. 2-4. Ionization Increasing in Energy as it Goes from Left to Right Across the Periodic Table Due to an Increased Nuclear Charge Resulting in Fringe Electrons Developing Stronger Bonds with Nuclei. (Source: 800px-Ionization_energy_periodic_table.svg_.png (800×489) (d1whtlypfis84e.cloudfront.net)

Chang and Overby (2017) describe ionization energy as the energy required to remove an electron from a gaseous atom or ion. Strong acids, which completely ionize in aqueous solutions, typically have low ionization energy. This means that they readily donate protons (H^+ ions) when dissolved in water. The atoms of strong acids, such as hydrochloric acid (HCl), hydrobromic acid (HBr), hydroiodic acid (HI), nitric acid (HNO_3), perchloric acid ($HClO_4$), and sulfuric acid (H_2SO_4) have lower ionization energies due to factors like high electronegativity and smaller atomic size. On the other hand, weak acids exhibit higher ionization energy, making it more difficult for them to donate protons. Weak acids like hydrogen sulfide (H_2S), carbonic acid (H_2CO_3), nitrous acid (HNO_2), acetic acid (CH_3COOH), hydrofluoric acid (HF), and phosphoric acid (H_3PO_4) only partially ionize in water, as shown in Figure 2-5. The higher ionization energy of their constituent atoms leads to partial dissociation and a lower concentration of hydrogen ions (H^+) in solution. The increase in ionization energy is the result of an increasing effective nuclear charge and decreasing atomic radius (Glenn, 2023; Chang and Overby, 2017). The stronger the attraction between a positively charged nucleus and the valence electrons, the more energy is required to remove an electron, resulting in higher ionization energy (Figure 2-4).

Understanding the relationship between ionization energy and the behavior of acids provides valuable insights into chemical reactions and processes. The periodic trend of increasing ionization energy across the periodic table helps explain the variations in acid strength and ionization behavior (Glenn, 2023; Chang and Overby, 2017).

Ionization energy refers to the amount of energy required to remove an electron from an atom or ion in its gaseous state. The previously mentioned movement across the periodic table increases the ionization energy because the effective nuclear charge and electron-electron repulsion both increase, making it more difficult to remove an electron. However, as you move down a group, the ionization energy generally decreases due to the increasing distance between the outermost electrons and the nucleus, resulting in a weaker attraction and easier removal of an electron. The weak acids below partially dissociate, releasing only a fraction of their protons.

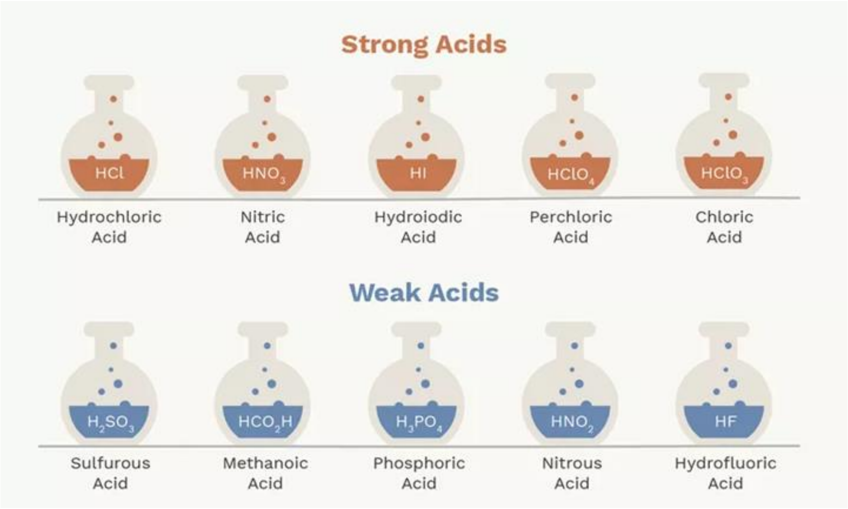


Figure. 2-5 The strong acids on the top row readily donate protons (H+) in solution.

Source:strong-and-weak-acids-603642-v2copy2-5b47abd0c9e77c001a395e55.png (768×512) (thoughtco.com)

The strength of an acid is determined by its ability to completely or partially dissociate into ions. This difference in dissociation behavior is related to the stability of the resulting ions and the strength of the acid-base equilibrium. Understanding these concepts provides insights into the reactivity and behavior of elements and compounds in chemical reactions and helps predict their acidic or basic properties (Figure 2-5).

2.6 Review of Background Research

A common criterion for the suitability of water for mixing concrete is the classic phrase, "If water is suitable for drinking, it is suitable for producing concrete." However, research suggests that this criterion may not be the most reliable basis for evaluation. Lamond et al. (2006) found that some waters, including water with low volumes of sugar or citrate flavoring, are satisfactory for drinking but do not effectively conglomerate with the concrete. In other words, water appropriate for combining concrete is not presently suitable for drinking (Lamond et al., 2006).

Cement is a chemical product that has adhesive properties that harden due to contact with water, resulting in high durability and resistance to water and moisture. Rawa et al. (2012) emphasized the role of cement in concrete as a binder for stone grains, stating that concrete does not in itself play a role in the strength of concrete. The authors also emphasized the importance of using high-quality stone materials in concrete production, particularly sand.

Because water is one of the main components in concrete, water plays a crucial role in enabling the necessary chemical reactions. Thus, water quality is of paramount importance. Lamond et al. (2006) focused on the potential effects of impurities in water during cement setting, suggesting that contaminated water, sewage, and saltwater with high salt content should never be used in concrete. They recommend the use of drinking water or water of equivalent quality.

Smith et al. (2018) found that water quality parameters such as pH and alkalinity significantly affect the workability and compressive strength of concrete. The authors assert that higher pH levels in water can adversely affect the strength of concrete, requiring a careful selection of water sources for concrete production.

Another study by Johnson and Brown (2015) investigated the impact of different water sources on the performance of concrete. They concluded that water with excessive mineral content, such as high levels of sulfates and chlorides, can lead to concrete deterioration over time. The authors recommended specific quality water standards be followed when selecting water for concrete production to ensure the long-term durability of concrete structures.

To summarize, the conventional notion linking the suitability of water for drinking with its appropriateness for concrete mixing may not hold true in all cases. Lamond et al. (2006), Smith et al. (2018), and Johnson and Brown (2015) shed light on the complexities of water selection in concrete production, emphasizing the need for a thorough evaluation of water quality parameters to attain high-quality and durable concrete.

Thavamalar (2009) conducted a study on the use of treated wastewater from a paper mill in the production of concrete. The results showed that using this wastewater resulted in concrete specimens achieving 90% of the compressive strength of specimens prepared with drinking water. It also reduced the slump and increased the setting time.

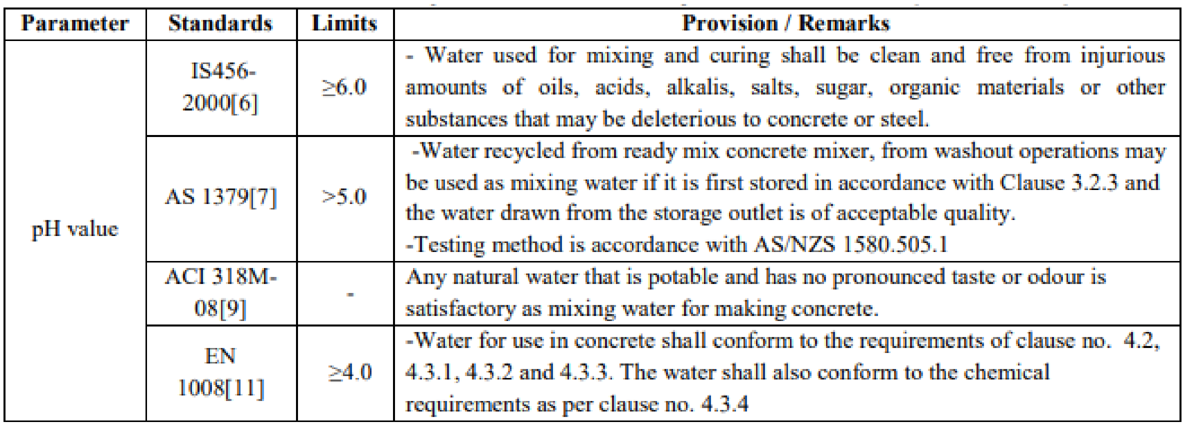
David (2013) studied the effects of seawater mixed with high-volume pozzolanic materials on the compressive strength of concrete. The use of seawater was considered risky due to the chloride (Cl) content, which can cause steel corrosion.

Alenezi (2010) investigated the use of tertiary treated wastewater in concrete production and found that it had no significant effect on the compressive strength of concrete.

Novil (2005) demonstrated that seawater should not be used as the required water in reinforced concrete or steel reinforcement due to the high risk of steel corrosion. On the other hand, long-term laboratory research conducted at the Institute of Ports and Airports in Yokosuka City, Japan indicates that the chloride content measured in seawater for concrete production has had minimal impact on concrete strength for the past 20 years. However, the negative effects of seawater usage have decreased with time (Otsuki, 2009), and the use of seawater in concrete mixing is considered risky due to the chloride content, which can cause steel corrosion. While some studies suggest that seawater usage should be avoided in reinforced concrete, long-term laboratory research has shown that the negative effects of seawater on concrete strength decrease over time. To summarize: The use of treated seawater in concrete production has shown promising results, achieving a compressive strength comparable to that prepared with drinking water.

Table 2-7 provides information on how to use mixing water from concrete mixer washout operations and natural water that is potable. Kucche et al. (2015) prepared this table based on safety standards of Australian, American, and British standards. They used coda, the ultrasonic coda wave comparison technique to assess the pH value of water in concrete production (Hafiz and Schumacher, 2018). However, using impure water still runs the risk of suffering from the corrosion of rebars, which limits its long-term life.

Table 2-7. pH values, standards, and water requirements for concrete mixing using coda (Source: Kucche et al. 2015, p. 3)

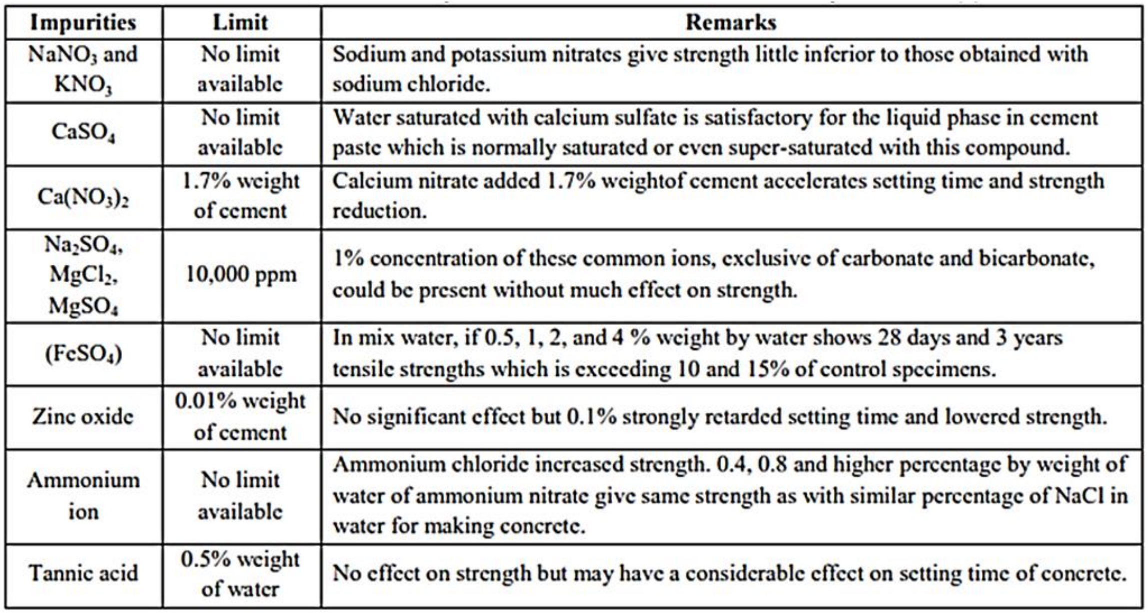


Parameter	Standards	Limits	Provision / Remarks
pH value	IS456-2000[6]	≥6.0	- Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel.
	AS 1379[7]	>5.0	-Water recycled from ready mix concrete mixer, from washout operations may be used as mixing water if it is first stored in accordance with Clause 3.2.3 and the water drawn from the storage outlet is of acceptable quality. -Testing method is accordance with AS/NZS 1580.505.1
	ACI 318M-08[9]	-	Any natural water that is potable and has no pronounced taste or odour is satisfactory as mixing water for making concrete.
	EN 1008[11]	≥4.0	-Water for use in concrete shall conform to the requirements of clause no. 4.2, 4.3.1, 4.3.2 and 4.3.3. The water shall also conform to the chemical requirements as per clause no. 4.3.4

The basic points of value from the Kucche et al. (2015) study are in Table 2.8.

Table 2.8 Limits and effects of dissolved chemical impurities in water

Source Kucche (2015), https://www.ijsrp.org/research-paper-0115/ijsrp-p3720.pdf



Impurities	Limit	Remarks
$NaNO_3$ and KNO_3	No limit available	Sodium and potassium nitrates give strength little inferior to those obtained with sodium chloride.
$CaSO_4$	No limit available	Water saturated with calcium sulfate is satisfactory for the liquid phase in cement paste which is normally saturated or even super-saturated with this compound.
$Ca(NO_3)_2$	1.7% weight of cement	Calcium nitrate added 1.7% weightof cement accelerates setting time and strength reduction.
Na_2SO_4, $MgCl_2$, $MgSO_4$	10,000 ppm	1% concentration of these common ions, exclusive of carbonate and bicarbonate, could be present without much effect on strength.
($FeSO_4$)	No limit available	In mix water, if 0.5, 1, 2, and 4 % weight by water shows 28 days and 3 years tensile strengths which is exceeding 10 and 15% of control specimens.
Zinc oxide	0.01% weight of cement	No significant effect but 0.1% strongly retarded setting time and lowered strength.
Ammonium ion	No limit available	Ammonium chloride increased strength. 0.4, 0.8 and higher percentage by weight of water of ammonium nitrate give same strength as with similar percentage of NaCl in water for making concrete.
Tannic acid	0.5% weight of water	No effect on strength but may have a considerable effect on setting time of concrete.

a) Natural water or freshwater seldom includes larger than 2,000 ppm of dissolved solids and is usually proper for producing concrete.

b) Water polluted with industrial wastes without suspended solids is also fit at low concentrations for producing concrete.

c) In natural water, much of the impurities' contents may be endured except for the alkali carbonates and bicarbonates, which may have considerable impacts even smaller than or similar to 2,000 ppm.

d) Other inorganic impurities of possible industrial origin which can be detrimental at average concentrations are sulfides, iodides, phosphates, arsenates, borates, and compounds of lead, zinc, copper, tin, and manganese are negatively influence concrete properties.

e) Organic impurities can also change concrete properties, mainly present in sugar (Kucche et al. 2015)

The first practical experiments and studies on magnetic field applications in cement, brick, and formwork were conducted by Russian researchers, yielding convincing and undeniable results shown in Table 2-8 (Venkatesan, 1998). Building upon these findings, further extensive studies were conducted by Russian researchers in 1993, introducing magnetic technology for concrete and cement production in global markets (Venkatesan, 1998). Subsequent investigations were performed by Beloretsk University in Beloretsk, Russia and Tulane University in New Orleans, LA, Amoco Corporation's Defense branch, and the Building Research Center affiliated with the US Navy, enabling successful utilization of magnetic behavior to solve related problems (Venkatesan, 1998; BS1818, part 116).

2.6.1 Effects of Different Water Sources on Concrete Performance

When magnetized seawater is used for cement mixing, favorable outcomes, including increased compressive strength of cement. However, using seawater requires a specific structural approach and the use of magnetic schemes in water reservoir systems can mitigate sedimentation issues in pumps and water pump stations. Unfortunately, the transportation of concrete mixtures over long distances leads to a reduction in the elastic properties of concrete, decreasing its durability, and energy costs increase when electromechanical vibrators are employed (Venkatesan, 1998; BS1818, part 122). Its best use is in cement grout, which when made with magnetic water (MW) increases its compressive strength by providing more hydrate crystals, creating a better compact filling space for cement particles, more contact points, and fewer voids compared to grout made with tap water (Hu and Deng, 2021).

Sandrolini and Franzoni (2001) investigated the production of mortar using concrete plant wastewater, evaluating its compressive strength against sulfates, efficiency, and setting time. The results indicated that the concrete produced with this wastewater exhibited 96% of the compressive strength of the control concrete samples (Ekolu and Dawneerangen, 2010; Sandrolini and Franzoni, 2001).

Another study examined concrete made with the wash water of concrete delivery trucks and concrete plants. The concrete made with wash water contained higher alkalinity and solid soluble substances than allowable in the ASTM C94-81 standard (ASTM 2017) and had more defects, lower matrix strength, and weaker matrices (Chatveera et al., 2006).

Meyer demonstrated in their study that to mitigate the negative effects of cement and concrete production, substituting a portion of cement with fly ash and utilizing recycled materials such as recycled aggregates, worn-out tires, glass, and industrial by-products, as well as using wastewater instead of drinking water, can contribute to achieving environmental sustainability in concrete production (Meyer, 2009).

Several studies have investigated the effects of using magnetically treated water and substituting fly ash for cement to test the efficiency and compressive strength of mortar and concrete. Sun (2002) conducted a study titled "Effectiveness of Magnetically Processed Water on Mortar and Concrete Containing Fly Ash." The results showed that the compressive strength of mortar specimens mixed with magnetically processed water increased compared to specimens prepared with regular water. The highest increase in concrete compressive strength was achieved when water passed through a magnetic field of 0.8-1.2 Tesla at lower curing ages.

Another study examined the production of concrete and mortar using concrete wash water. Sandrolini & Franzoni (2001) found that the concrete produced with concrete wash water had a high compressive strength, reaching 90% of the compressive strength of the control concrete specimens.

Ashtekar and Jawalkar (2018) found that magnetized water increases the compressive strength of concrete by up to 14%. They tested three different grades of concrete (M25, M30, and M35) in magnetized water. One mix was prepared without magnetized water. Compressive strength tests on the specimens made with magnetized water showed an increased compressive strength of up to 14%.

2.6.2 Tests on Concrete Compressive Strength, Corrosion, and Water Quality

Several tests were run on concrete compressive strength and corrosion, as well as water quality. The following gives some examples:

1) Corrosion and Compressive Strength: An experiment investigating corrosion effects on the compressive strength of concrete was conducted to assess the compressive strength of corroded concrete using an accelerated corrosion test. Corrosive solutions containing hydraulic acid with pH 2 and pH 3, sodium chloride solutions with concentrations of 10% and 20%, and sodium sulfate solutions with concentrations of 10% and 20% were used as corrosive mediums. The mechanical properties, including compressive strength, stress-strain relation, and elastic modulus, were evaluated for all the corroded specimens. The study revealed that specimens exposed to hydraulic acid solution exhibited more severe corrosion. As the corrosion progressed, the stress-strain curve became gentler. The compressive strength and elastic modulus of the specimens decreased with the increase of exposure days. Moreover, the failure mode of tensile strength of corroded specimens differed from that of uncorroded specimens (McPolin et al., 2009).

2) Effect of Sodium Chloride on Concrete Performance and Corrosion: Wei Sun et al. investigated the effect of sodium chloride on concrete performance, particularly its corrosion properties. The study examined the impact of sodium chloride on the corrosion of concrete and its mechanical behavior. The results showed that at the initial stage of corrosion, there was a slight increase in compressive strength, and the degree of strength increase was linked to the concentration of the sodium chloride solution. However, as corrosion progressed, the strength of the concrete decreased (Sun et al., 2002).

3) Water Quality for Concrete Production. Rawa et al. (2012) conducted a study on the appropriate water quality for concrete production in general. The study presented different intervals of quality parameters; however, these intervals were not statistically verified by a laboratory. Further research is needed to investigate the specific effects of water quality on concrete properties and performance.

In summary, the literature indicates that corrosive solutions, such as hydraulic acid, sodium chloride, and sodium sulfate can negatively impact the compressive strength and mechanical properties of concrete. The severity of corrosion and the concentration of corrosive solutions play a significant role in determining the extent of strength reduction. Additionally, the quality of water used in concrete production is a crucial factor that requires further investigation to ensure optimal concrete performance.

2.7 Impact of Environmental Factors on Concrete Performance

There are several environmental factors to consider. The following are some of the most important.:

1) **Corrosion Effects on Concrete:** The corrosive nature of certain environments can significantly affect the mechanical properties of concrete. Experimental studies have shown that exposure to corrosive solutions, such as hydrochloric acid, sodium chloride, and sodium sulfate, leads to a decrease in compressive strength, stress-strain relations, and the elastic modulus of concrete specimens. The severity of corrosion is directly proportional to the deterioration of mechanical properties. Furthermore, the failure mode of tensile strength in corroded specimens differs from that of uncorroded specimens (McPolin et al., 2009)

2) I**nfluence of Temperature on Concrete Behavior:** Temperature exposure has a considerable influence on the mechanical behavior of concrete. Specimens subjected to high temperatures for varying durations demonstrate a decrease in compressive strength and split tensile strength. The reduction in strength is more pronounced with prolonged exposure to elevated temperatures. Moreover, concrete mixes with a lower water-to-cement ratio exhibit higher compressive strength compared to mixes with a higher ratio (Peng et al., 2022).

3) **Seawater and Sea Sand in Concrete Production**. The utilization of seawater and sea sand in concrete production has attracted significant attention, especially for offshore and littoral projects. Research has shown that incorporating seawater and sea sand without desalination can be beneficial, as freshwater and river sand resources are limited. The use of seawater and sea sand leads to an initial increase in compressive strength due to the accelerated chloride ion effect on cement hydration. However, in the long term, the presence of salts in

seawater contributes to lower strength and reduced performance of concrete. Magnesium sulfates present in seawater result in expansive crystallization and subsequent leaching, further diminishing the concrete's strength (Xiao et al., 2017; Gokulanathan et al., 2021).

4) **Influence of Total Dissolved Solids (TDS) in Water.** TDS content in water has always impacted the performance of fresh concrete.

5) **Higher TDS concentrations**. A higher TDS content increases the specific surface area of fine materials in concrete. This leads to a reduced permeability to chloride ions, which are negatively affected by elevated TDS levels (Gokulanathan et al., 2021).

6) **Water pH and its Effects.** Water pH plays a significant role in the chemical environment of concrete. Neutral water (pH 7) has no reactive power on its own but quickly adjusts to become acidic or alkaline depending on the surroundings. Acidic water (pH 7-0) is associated with long-term health issues, while alkaline water (pH 7-14) can neutralize acidic environments. The European standard recommends a pH range of 8.5 to 9.5 for drinking water (Yavari, 2006).

In summary, the mechanical behavior of concrete is influenced by various factors such as corrosion, temperature exposure, and water quality. Corrosion in aggressive environments leads to a decrease in compressive strength and elastic properties of concrete. High-temperature exposure reduces the compressive and split tensile strengths of concrete specimens, with lower water.

2.7.1 Water Quality and its Impact on Concrete Strength

The following list covers two of the major concerns affecting water quality and its use in concrete production.

1) **Long-Term Effects of Chloride Content in Water.** Long-term research conducted at the Japan Institute of Ports and Airports indicates that the chloride content in water used for concrete production has minimal impact on concrete strength after a period of 20 years. This suggests that seawater can be effectively used in concrete production over extended durations without significant detriment to concrete strength (Otsuki, 2009).

Feasibility of Gray Water as Mixing Water. A study evaluating the feasibility of using gray water as an alternative source of mixing water found that its use resulted in reduced initial and final setting times of concrete. However, the setting time remained within acceptable limits. Furthermore, the study showed that the compressive strength of concrete increased by 12.4% and 11% at 7 and 28 days, respectively, compared to the control sample. This increase in alkalinity in the gray water was attributed to improved compressive strength (Peche et al., 2014).

In summary, additional research findings suggest that the long-term effects of chloride content in water on concrete strength may not be significant after an extended period. Seawater can be utilized effectively in concrete production over extended durations. Furthermore, the use of gray water as a mixing water source shows promising results in terms of setting time reduction and improved compressive strength, provided the alkalinity remains within an acceptable range. These findings contribute to a better understanding of the influence of water quality on concrete performance, aiding in the development of more sustainable and durable concrete structures.

Nikhil & Sushma et al. (2014) examined the effect of different mixing water sources, including drinking water, groundwater, and untreated municipal wastewater on the strength properties of concrete. Replacing drinking water with untreated wastewater as mixing water for concrete resulted in a significant reduction in concrete compressive strength (approximately 25%), tensile strength (approximately 13%), and flexural strength (approximately 10%).

Wastewater from municipal sewage treatment plants can be used as both mixing water and curing water. This can lead to a reduction in compressive strength at 7, 14, and 28 days for different mix designs. This reduction exceeded 10% when compared to control specimens, and the excessive concentration of bicarbonates in the wastewater has been identified as the cause.

The use of drinking water and recycled water in concrete production. The use of recycled water in concrete production has been known to improve the setting time and compressive strength of concrete. The alkalinity and chloride content in the concrete are evaluated using pore structure and leaching tests. The tests mentioned in this dissertation show how researchers and contractors determine if different types of mixes are suitable for concrete construction.

To summarize, the literature review in this dissertation demonstrates the influence of different types of mixing water on the properties of concrete. The use of gray water as mixing water showed promising results, with a decrease in initial and final setting times and an increase in compressive strength. However, the alkalinity of gray water beyond permissible limits was identified as a contributing factor to the strength increase. Conversely, using untreated wastewater as mixing water led to a significant reduction in the compressive, tensile, and flexural strengths of concrete. The excessive concentration of bicarbonates in wastewater was identified as the cause of this reduction. The use of wastewater as both a mixing and curing water also resulted in reduced compressive strength. On the other hand, the use of recycled water in concrete production improved the concrete setting time and compressive strength. Finally, the quality of the concrete met the necessary standards.

2.7.2 Chloride Effect on Mechanical Properties of Self-Compacting Concrete

The following will cover the use of municipal wastewater and seawater in concrete production.

Evaluation of Treated Municipal Wastewater for Concrete Production: In a comprehensive laboratory investigation, Mehrdadi (2009) assessed the potential of using treated municipal wastewater in the preparation and maintenance of concrete. Concrete cubes were prepared using treated wastewater from primary, secondary, and tertiary treatment units; then, the compressive strength of the wastewater treated cubes were compared with the compressive strength of potable water-treated cubes at 7 and 28 days. The organic matter levels in the mixing water were within acceptable limits. This was a requirement before the secondary treatment with treated wastewater could be applied to the municipal wastewater. When the wastewater-treated cubes were compared with the potable water cubes, the reduction in concrete strength was less than 10%. Additionally, the effect on the 7-day compressive strength was more pronounced compared to the 28-day compressive strength. Therefore, considering the difference in compressive strength between 28-day concrete and concrete prepared using potable water, it is not expected that long-term durability properties would exhibit a substantial deviation from standard concrete strength.

Chloride Influence on Mechanical Properties of Self-Compacting Concrete: To investigate the impact of chloride on the mechanical properties of self-compacting concrete, Sarhangian (2015) conducted a comprehensive laboratory study. The experiment involved examining the elastic modulus and compressive strength of concrete samples subjected to seawater exposure and the use of Type 5 cement during the curing period. The research objective was to assess the changes in compressive strength and elastic modulus over the concrete's curing duration due to seawater exposure and specific cement composition.

In summary, the literature review discusses the feasibility of using treated municipal wastewater in concrete preparation and maintenance. It highlights the importance of considering TDS concentrations and pH values and their impact on concrete performance. The reviewed studies emphasize the significance of secondary treatment in wastewater purification and suggest that within acceptable organic matter limits, the reduction in concrete strength compared to potable water is less than 10%.

2.7.2 Chloride Effect on Mechanical Properties of Self-Compacting Concrete

In a laboratory experiment, Miri (2007) investigated the effects of magnetic technology on seawater. The study aimed to examine the impact and performance of ionized seawater from the salty and fresh waters of the Arabian Sea on compressive strength, fresh concrete efficiency, and cement consumption. The experimental results provided insights into the influence of magnetic technology on seawater and its potential implications for concrete applications in marine engineering. According to Ashrafi (2014), another study explored the feasibility of using sea water as a component in concrete, particularly in combination with mineral additives such as iron furnace slag ash. The research findings revealed positive outcomes regarding the utilization of sea water as a mixing water in concrete when combined with mineral additives. The empirical data demonstrated that the addition of mineral additives to concrete increased the corrosion resistance of reinforcing steel bars by reducing oxygen and preventing chloride accumulation around the steel bars. Hakimzadeh (2009) investigated the durability of reinforced concrete in a severely corrosive marine environment, focusing on the concrete's position relative to the water level of Urmia Lake. The results indicated that the intensity and rate of corrosion of the reinforcement were higher in the splash zone of the concrete casting. In contrast, in the submerged zone, although the potential for corrosion of the embedded reinforcement was very high, the corrosion rate was negligible due to insufficient oxygen availability. Consequently, the probability of corrosion was low in the submerged zone.

To summarize, the literature review encompasses three studies focusing on the use of seawater in concrete and its impact on various concrete properties. Miri (2007) conducted a laboratory experiment to examine the influence of magnetic technology on seawater, particularly its effects on compressive strength, fresh concrete efficiency, and cement consumption. Ashrafi (2014) explored the feasibility of using seawater as a blending water in concrete along with mineral additives, highlighting the positive effects on corrosion resistance. Hakimzadeh (2009) investigated the durability of reinforced concrete in a severe marine environment and identified variations in the corrosion rate based on the concrete's position relative to the water level. These studies provide valuable insights into the use of seawater in concrete applications and its potential for enhancing concrete performance and durability in marine environments.

2.7.3 Evaluation of Non-Potable Water Sources in Concrete Production

According to Gokulanathan et al. (2021), their comprehensive review focuses on the fresh and hardened properties of concrete mixed and cured with five different non-potable water sources. The study examines the effects of replacing potable water with alternative sources in concrete production. The five non-potable water types considered are 1 seawater, 2) wash water from a Ready-Mix concrete plant, 3) grey water, 4) treated sewage wastewater, and magnetized water. The research results indicate that using seawater as a mixing medium can lead to an increase in compressive strength with a 10% improvement at early ages (up to 7 days) and a significant 24% enhancement at 56 days. However, higher concentrations of TDS, specifically at levels of 50,000, can adversely affect the performance of fresh concrete. Notably, the comparison of different water sources was not conducted under identical conditions, and the pH boundary ranges were consistent among the samples. Furthermore, the study did not consider the effect of TDS on the water-to-cement ratio beyond 0.5 (ranging from 0.35 to 0.50).

Wegian (2010) investigated the effect of seawater for mixing and curing structural concrete to determine its impact on concrete strengths, including compressive strength, tensile strength, flexural strength, and bond strength. The experimental study involved 16 different concrete mixes, with six mixes mixed and cured in freshwater, six mixes mixed and cured in seawater, and four mixes mixed with freshwater and cured in seawater. Results indicated that concrete mixes mixed and cured in seawater exhibited higher compressive, tensile, flexural, and bond strengths compared to those mixed and cured in freshwater, particularly in the early stages between 7 and 14 days. Moreover, the strengths of concrete mixes mixed and cured in freshwater showed a gradual increase after 28 and 90 days. The study also emphasized that cement content in the concrete mixes significantly affected the concrete strengths and durability. However, it should be noted that the study did not consider the effect of water to cement ratio by TDS, and the TDS boundary ranges were the same, while the pH boundary ranges were consistent at 8.2.

Gokulanathan et al. (2021) focused on the effects of using five different non-potable water sources for mixing and curing concrete. These sources included seawater, wash water from ready-mix concrete plants, grey water, treated sewage wastewater, and magnetized water. The research, based on a comprehensive review of 75 published articles, discussed the outcomes of replacing potable water with these alternative water sources in concrete production. The study found that seawater mixing led to an increase in compressive strength with a significant improvement observed in the early ages of concrete (up to seven days) and a further increase at 56 days. However, higher concentrations of total dissolved solids (TDS) in the water negatively affected the performance of fresh concrete. It should be noted that the comparisons of the different water sources were not conducted under the same conditions, and the study did not consider the effect of water-to-cement ratio by TDS beyond the range of 0.35 to 0.50.

On the other hand, in the research conducted by Wegian (2010), the objective was to evaluate the impact of curing conditions, specifically freshwater versus seawater on the strengths of structural concrete. Sixteen concrete mixes were examined. Some were mixed and cured in freshwater, some in seawater, and others mixed in freshwater but cured in seawater. The findings revealed that concrete mixes mixed and cured in seawater exhibited higher compressive, tensile, flexural, and bond strengths compared to those mixed and cured in freshwater, particularly at the early ages of 7 and 14 days. However, the strengths of concrete mixes mixed and cured in freshwater showed a gradual increase over time, with significant improvements observed after 28 and 90 days. The study also highlighted the significant influence of cement content on concrete strengths and durability. Similar to the previous study, water-to-cement ratio effect of TDSs was not considered, and the TDS boundary ranges were consistent, while the pH boundary ranges remained the same at 8.2.

In summary, both studies examined the effects of using non-potable water sources, including seawater, in concrete production. Gokulanathan et al. (2021) found that seawater mixing increased compressive strength, but higher TDS concentrations had a negative impact on fresh concrete performance. Wegian (2010) demonstrated that concrete mixed and cured in seawater exhibited higher strengths compared to those mixed and cured in freshwater, particularly in the early ages. However, both studies had limitations, including variations in testing conditions and the omission of water-to-cement ratios by TDS analysis beyond a certain range. These findings highlight the importance of further research and standardized testing methodologies to fully assess the impact of non-potable water sources on concrete properties.

2.7.4 Influence of Water pH on Compressive Strength of Concrete

Tiwari et al. (2014) investigated the effect of saltwater on the compressive strength of concrete. Concrete cubes were cast using both freshwater and saltwater, with a water-cement ratio of 0.45. Their study found that the average compressive strength of concrete using freshwater ranged from 27.12 to 39.12 N/mm2, while the average compressive strength of concrete using saltwater ranged from 28.45 to 41.34 N/mm2. Notably, no reduction in strength was observed when using saltwater for casting and curing concrete. It should be noted that the study did not consider the effect of the water-to-cement ratio by total dissolved solids (TDS), and the pH boundary ranges were the same.

Nikhil et al. (2014) tested the impact of water quality on the strength properties of concrete with the goal of replacing drinking water with untreated wastewater. Different types of mixed water, including drinking water, groundwater, and untreated municipal wastewater, were used in the experimental study. The results revealed that the replacement of drinking water with untreated wastewater as the mixing water led to a reduction in various concrete strength indices. Compressive strength decreased by approximately 25%, tensile strength decreased by about 13%, and flexural strength decreased by approximately 10%. However, the study did not consider the TDS effect of the water-to-cement ratio, and the pH boundary ranges were the same. The TDS levels considered in the study ranged from around 300 mg/l to 600 mg/l.

Akomah et al. (2018) investigated the pH effects of water on the compressive strength of concrete. Water sources included three different water types--from well water, aquarium water, seawater, treated water, and Kakum River water. All were used in separate mixing tests. The results indicated that concrete specimens produced using the aquarium water and Amissano well water exhibited lower compressive strengths compared to the other water sources. This decrease in strength can be attributed to the high acidity of these two water sources, with the aquarium water being 10 times more acidic. The Amissano well water was 20 times more acidic than the other sources. Interestingly, despite the seawater being 10 times more basic than the other water sources, its strength was not significantly influenced. The study focused solely on the pH factor and did not consider the effect of the water-to-cement ratio by total dissolved solids (TDS). Additionally, the TDS boundary ranges were the same.

In summary, these studies highlight the importance of water quality, including salinity, pH, and the presence of contaminants, in determining the strength properties of concrete. While some water sources may have adverse effects on concrete strength, others may not show significant differences. Understanding the impact of water quality on concrete performance is crucial for ensuring the durability and reliability of concrete structures.

2.7.5 Recent Research on Water Quality and Concrete Performance

Gudipudi et al. (2020) conducted an experimental study to investigate the effect of different pH waters on the compressive strength and tensile strength of concrete. The study focused on three pH levels (4, 7, and 9) and examined the strength properties of concrete cubes and cylinders at various curing durations (3 days, 14 days, and 28 days). The results indicated that there was not much variation in the compressive strengths among the three pH levels after three days of curing, suggesting that the water pH had a limited influence on early strength development. However, after 7 and 28 days of curing, a slight gradual increase in strength was observed for concrete exposed to pH 4 and pH 9 waters. Gudipudi et al. (2020) noted that the neutral, acidic, and alkaline nature of the waters might have played a role in this strength increase trend. The study focused solely on the effect of pH during the initial blending stage and did not consider its impact during the curing process. The TDS effect on water-to-cement ratio was not considered.

Ojo (2019) conducted a study to evaluate the effect of water quality on the compressive strength of concrete. Various water sources were used as mixing water, including well water, borehole water, rainwater, wastewater, and river water. Compressive tests were performed on hardened concrete samples at 7, 14, and 28 days. The results indicated that the physiochemical characteristics of the tested water samples fell within the acceptable limits defined by the World Health Organization (WHO, 2022), except for elevated levels of iron, magnesium, and lead, which exceeded the acceptable limits. Workability tests showed that the source of water used for concrete mixing did not significantly affect the workability of the concrete. WHO also revealed that regardless of the type of water used, the compressive strength of the concrete increased with age. Most importantly, the TDS effect on water-to-cement ratios by total dissolved solids (TDS) was not considered, and the TDS boundary ranges were under 100 mg/L.

In summary, Gudipudi et al. (2020) highlights that water pH has limited influence on early strength development in concrete, with a slight gradual increase in strength observed at higher pH levels after longer curing durations. On the other hand, Ojo (2019) emphasized that water quality, specifically elevated levels of certain elements, can affect the compressive strength of concrete. However, the workability of concrete is not significantly impacted by the water source. Both Gudipudi et al. (2020) and Ojo (2019) provide valuable insights into the relationship between water quality and concrete strength, but further research is needed to explore the effects of water-to-cement ratios and total dissolved solids (TDS) on concrete properties.

Hama et al. (2022) investigated the effects of water quality on the compressive strength of concrete. Eight different types of water were used, including water with varying impurity levels (71 UTN, 250 UTN, 1,000 UTN). They used well-sourced water, acidified water, and alkaline water with potable water as a reference were used as concrete mixing water. The compressive strength of the concrete was measured at 7, 14, and 28 days of age. The results reveal that using alkaline water as mixing water leads to the lowest compressive strength at 7 days, while water with 250 UTN impurity level yields the highest compressive strength. Similarly, at 14 days, alkaline water results in the lowest compressive strength, while water with 71 UTN and 250 UTN impurity levels exhibits the highest compressive strength. At 28 days, water with a 71 UTN impurity level and acidic water show the lowest compressive strength, while magnetic water and water with a 250 UTN impurity level demonstrate the highest compressive strength. It is important to note that the study did not compare the results under the same conditions, and the effect of water-to-cement ratio by total dissolved solids (TDS) was not considered above 0.5 (0.35 - 0.50).

In summary, the study by Hama et al. (2022) explores the effects of water quality on the compressive strength of concrete. Their test results indicate that different types of water used for concrete mixing can have varying effects on compressive strength at different ages. Alkaline water generally results in lower compressive strength, while water with lower impurity levels tends to yield higher compressive strength. However, it is important to conduct further studies under standardized conditions to accurately compare the effects of different water qualities. Additionally, the consideration of water-to-cement ratio by total dissolved solids (TDS) is crucial for a comprehensive understanding of the relationship between water quality and concrete strength.

2.8 Chapter Summary

Based on the background research review, several conclusions can be drawn regarding the influence of water quality on the strength properties of concrete:

1. **Water Quality Impact:** Water quality has a significant influence on the strength properties of concrete. Different types of water, such as seawater, grey water, and alternative water sources, have been studied to assess their effects on concrete performance, revealing that grey water and certain alternative water sources have shown promising results in maintaining or even enhancing concrete strength properties.
2. **Replacement of Drinking Water**: The studies reviewed indicate that drinking water can be replaced with alternative water sources, such as seawater or grey water in concrete production. This substitution offers the potential for more sustainable water use in construction projects.
3. **Total Dissolved Solids (TDS) Effect:** The concentration of total dissolved solids (TDS) in water has been found to impact the performance of fresh concrete. Higher TDS concentrations can increase the specific surface area of fine materials in concrete and reduce concrete performance.
4. **pH Influence:** The pH level of water has a separate effect on the compressive strength of concrete. Acidic water with a pH below 7 and alkaline water with a pH above 7 can both impact concrete strength properties. Acidic water over the long term may cause diseases and have negative effects on concrete, while

alkaline water can neutralize acidic environments and potentially improve concrete performance.

To summarize, water quality, particularly water with TDS and pH factors, plays a crucial role in determining the compressive strength and overall performance of concrete. Researchers have explored the use of alternative water sources and their effects on concrete, demonstrating their potential for sustainable practices in the construction industry. Understanding the influence of water quality on concrete properties is essential for producing durable and resilient structures. Further research is needed to explore the specific mechanisms through which water quality parameters affect concrete strength and to develop guidelines for optimal water usage in concrete production.

Chapter 3 Methodology

3.1 Introduction

This chapter presents the methodology and experimental procedures used in this research. The required materials for preparing concrete samples are described. How to determine particle size distribution is one of the most important preparation methods. The proposed mix designs for creating different concrete specimens are outlined, and information is provided on how equipment is used to conduct compressive strength tests according to the concrete industry's relevant standards.

3.2 Research Steps

3.2.1 Steps

This research methodology in this dissertation involves various stages used to collect data and address research questions. The following are the main steps of this research process:

- **Literature review:** Conducting a comprehensive review of relevant literature on a topic helps all research group members to gain a thorough understanding of existing knowledge and research findings.
- **Theoretical framework:** Developing a theoretical framework provided a conceptual basis for this research and guided the investigations.
- **Instrumentation and laboratory setup**: Acquiring, preparing, and maintaining the necessary laboratory equipment and tools to construct and test concrete samples saved time and provided a safer and more productive laboratory experience.
- **Experimental testing:** Conducting necessary experiments on the concrete samples were prepared with made water, including various tests and measurements.

- **Data analysis:** Analyzing and interpreting the results obtained from the experimental testing is ongoing and everyone received instruction on how to attain appropriate statistical and analytical methods.
- **Report writing:** Compiling and documenting this research findings, conclusions, and recommendations provided a comprehensive research report included in this dissertation.

3.2.2 Data Collection Method

The data collection method in this research involves two main approaches: library-based research and laboratory experiments. In the first phase, data is collected through an extensive literature review, including books, catalogs, research papers, theses, and scientific journals. This information was organized into personal and shared files that were available to everyone who participated in this research, with an emphasis on concrete mix design, testing methods, and relevant standards such as ASTM, AASHTO, etc.

The second phase focuses on laboratory experiments conducted on various concrete samples prepared with different types of water. The results obtained from these experiments were then analyzed and compared using numerical analysis, tables, and relevant graphs. This analysis helps in interpreting the data and drawing meaningful conclusions. It is important to note that the necessary information for this research is gathered through library-based research methods, which involve studying books, catalogs, research papers, theses, journals, and other relevant sources. Additionally, internet research and search methods were utilized to gather relevant data from online sources. By employing these data collection methods, I was able to gather comprehensive and reliable information to address this research objectives effectively.

3.2.3 Data Analysis Method

To investigate the compressive strength of concrete prepared with tap water, made water, and materials infused with made water, laboratory evaluations were conducted. To achieve the research objectives, common concrete tests and evaluations were performed. The tests included the slump test to measure the consistency of concrete, sieve analysis to determine the particle size distribution of aggregates using the ASTM C136-08 standard (ASTM 2019), moisture content determination using the oven-drying method, concrete mixing using a concrete mixer device, and the concrete cube compression test using a compression testing machine. The obtained data from these tests will be analyzed to assess the performance and optimize the concrete mix design. Statistical analyses included multiple regression analysis, regression model predictions, and coefficient estimates. I compared results and interpreted advancements based on journal articles and reports. This research helped me to draw meaningful conclusions and make informed recommendations.

By employing these analytical methods, the compressive strength of concrete prepared with different types of water can be evaluated based on the effectiveness of laboratory tests designed to meet our research objectives.

3.3 Materials Used in the Dissertation

The materials used for the experiments and their corresponding specifications and standards are depicted in the accompanying photographs.

Figure 3-1 Aggregates Used in Experiments

Figure 3-2 Materials Used in Study

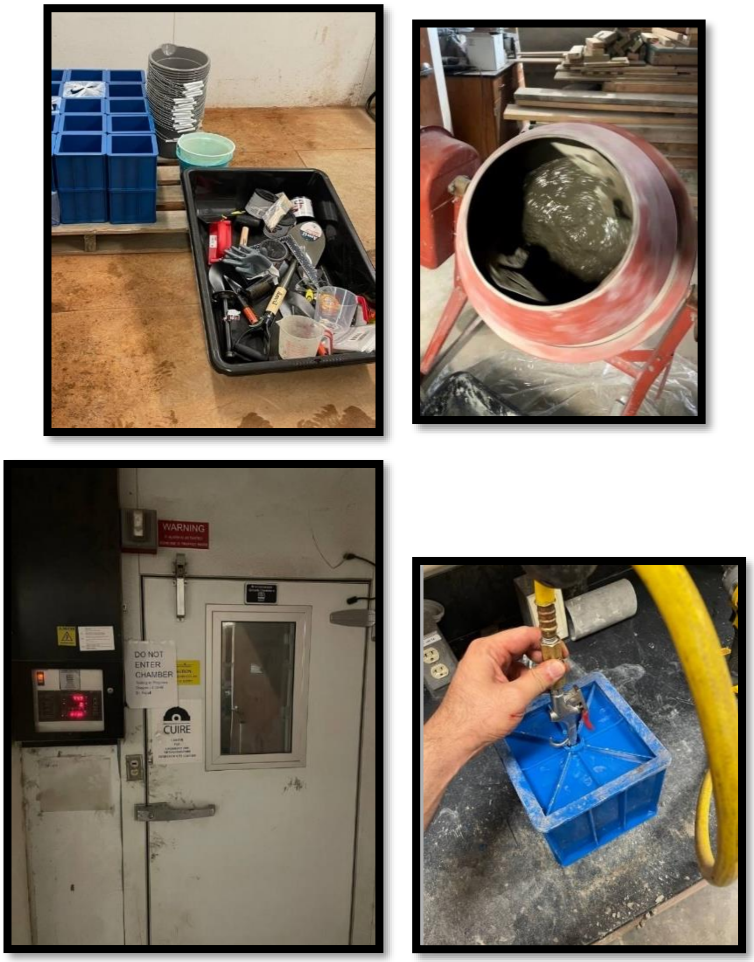


Figure 3-3 Equipment Used in Study

3.3.1 Aggregates Used in Experiments

As mentioned earlier, coarse, and fine aggregates were utilized in the construction of concrete specimens with different mix designs based on various tests conducted in this research. The coarse and fine aggregates used to construct our specimens were sourced from Sakrete of North America LLC in Charlotte, NC (Sakrete 2023) as shown in Figure 3-1 and in Figure 3-2. Sakrete is a well-known and reputable supplier of construction materials. The aggregate shapes obtained from Sakrete are fractured or angular (not flat or elongated), which are the most suitable for concrete production. The texture of the aggregate particles are compact and non-porous, indicating their strength and durability. This research benefited from the reliable performance of the Sakreet aggregates.

3.3.1.1 Sampling of Aggregate Materials

Accurate and precise sampling plays a crucial role in the preparation of concrete specimens with different mix designs. In this dissertation, the sampling of aggregates was conducted in accordance with the ASTM D75/D75M standard (ASTM, 2021), as shown in Figure 3-3. It is important to carefully remove larger-sized aggregates from the sample to ensure that the final samples truly represent the aggregates used in the concrete and satisfy the permissible range defined by regulations. This process is accomplished through the quartering method. As a common and acceptable approach for sampling various aggregates, the sample is first thoroughly mixed with all the collected aggregates and spread in a 75 or 100-millimeter layer. Then, the sample is divided into four equal parts, and the two opposite parts are mixed together to form the final sample for testing.

3.3.1.2 Optimal Gradation of Concrete Aggregates

The physical characteristics of aggregates play a crucial role in the performance of concrete. In the context of this dissertation, the aggregates sourced from Sakrete exhibit a fractured and angular appearance as specified by the ASTM C33/C33M standard (ASTM 2018).

The proper gradation of aggregates, following ASTM C136-08 standard (ASTM, 2019), guarantees optimal size distribution and adherence to industry-accepted criteria. The compact and non-porous texture of the aggregate particles further enhances their strength and resistance to permeability, promoting a strong interlocking effect within the concrete matrix.

This interlocking effect significantly improves the bond between the aggregates and the cement paste, resulting in enhanced mechanical properties such as compressive strength and durability.

By sourcing aggregates from Sakrete (2023) and following ASTM standards, my research underscores the importance of aggregate characteristics in concrete performance. The combination of fractured and angular aggregates with proper gradation ensures an optimized concrete mix, leading to improved workability, strength, and durability. Moreover, the adherence to ASTM standards guarantees consistency, reliability, and compatibility with industry-accepted criteria.

To summarize, this dissertation research emphasizes the significance of aggregate physical characteristics, specifically those obtained from Sakrete while following ASTM standards. The fractured and angular appearance of the aggregates, as well as their compact and non-porous texture, contribute to their strength and resistance. By adhering to ASTM guidelines for aggregate selection and gradation, the concrete mix design can meet the desired specifications, resulting in structures with enhanced workability, strength, and durability. It is crucial to obtain accurate and reliable results for this dissertation by ensuring the use of high-quality materials and adhering to the specified standards, as this will contribute to the credibility and validity of the research findings.

3.3.1.3 The Moisture Content of Coarse and Fine Aggregates

Specified in ASTM C566-19 (2019). In this method, a weighed sample of moist aggregate is dried in an oven. By comparing the initial and final weights, both the total moisture content and surface moisture content can be calculated. The total moisture content of the aggregates can be calculated using the following Eq. (3.1):

$$\text{Total Moisture Content (\%)} = [(\text{Initial Weight (including surface and internal moisture)} - \text{Dry Weight}) \,/\, \text{Dry Weight (After removing all moisture)}] \times 100 \qquad (3.1)$$

Notably, only the surface moisture of the aggregates contributes to the water content of the concrete mix, while the absorbed moisture does not play a role in the concrete. The surface moisture content of the aggregates can be obtained by subtracting the absorbed moisture from the total moisture content. The absorbed moisture of the coarse and fine aggregates can be calculated following the methods outlined in ASTM C127-15 (2015) and ASTM C128-15 (2015), respectively.

The following Eq. (3.2) is used to calculate the surface moisture content (SMC) of aggregates and is given as:

$$\text{Surface Moisture Content (\%)} = (\text{Total Moisture Content} - \text{Absorbed Moisture Content}) \,/\, \text{Dry Weight of Aggregates} \times 100 \qquad (3.2)$$

In this equation:

- Total Moisture Content refers to the moisture content of the aggregate sample, which includes both the absorbed moisture and the surface moisture.
- Absorbed Moisture Content refers to the moisture that is absorbed within the pores of the aggregate particles, determined using ASTM C127-15 (2015) for coarse aggregates and ASTM C128-15 (2015) for fine aggregates.
- Dry Weight of Aggregates is the weight of the aggregate sample after it has been dried to remove all moisture.

Partial moisture content refers to the amount of moisture present in a material or substance relative to its dry weight. It is expressed as a percentage and is commonly used in various industries and scientific fields to measure and assess the moisture content of different materials. To determine the partial moisture content of a sample, you need to measure the weight of the moisture within the sample and compare it to the weight of the dry sample. Eq. (3.3) calculates partial moisture content.

$$\text{Partial Moisture Content (\%)} = (\text{Weight of Moisture} / \text{Weight of Dry Sample}) \times 100 \tag{3.3}$$

The weight of moisture can be obtained by measuring the weight difference before and after drying the sample. The weight of the dry sample is obtained by completely removing all moisture from the sample through a drying process. The results of the tests for determining the moisture content of the aggregates are presented in the Table 3-1:

Table 3-1 Aggregate Moisture Content

Aggregate Type	Total Moisture Content (%)	Partial Moisture Content (%)	Surface Moisture Content (%)
Coarse Aggregate	0.68	0.61	0.32
Fine Aggregate	0.73	0.22	0.48

Figure 3-4 Aggregates Inside of Oven

The moisture content of the aggregate is a crucial factor that directly relates to the research objectives of this dissertation. Figure 3-4 shows aggregates inside oven. The moisture content affects the workability and water-cement ratio of the concrete mix, which in turn affects the compressive strength, durability, and overall performance of the concrete. By accurately determining and controlling the moisture content of the aggregate, the strategy was to optimize the concrete mix design and achieve the desired strength and performance characteristics. The efforts to control moisture helped me in my investigation and evaluation of the impact of moisture content on the properties of concrete aligning with the specific objectives of this dissertation.

3.3.1.4 The Specific Gravity of Aggregates

The specific gravity of aggregates is an important parameter that influences the overall density and quality of concrete. It is determined by comparing the weight of an aggregate to the weight of an equal volume of water. ASTM C29/C29M-17a (ASTM 2017) provides standard methods for measuring the specific gravity of aggregates. The rodding method is commonly used for coarse aggregates, where the sample is compacted by rodding and weighed.

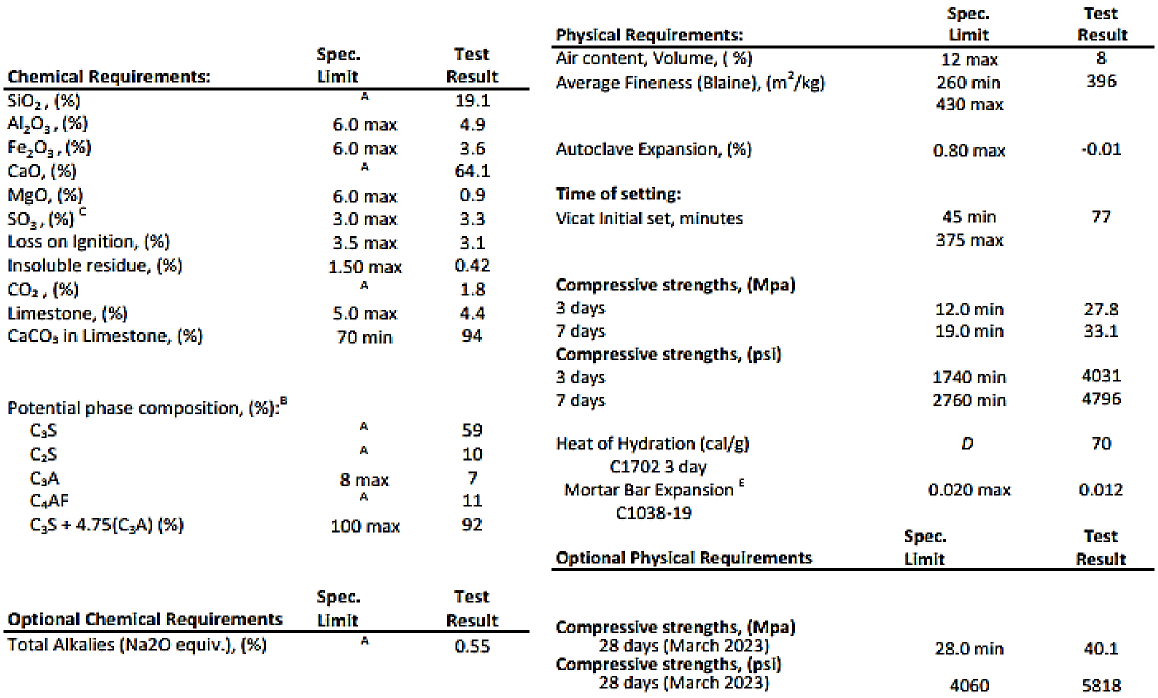
Figure 3-5 Rodding Method and Vibration Table Shaker

For fine aggregates, the shaking method is employed when the sample is placed in a container and shaken using a vibration table shaker to settle the particles before weighing illustrated in figure 3-5. These methods ensure accurate and consistent measurements of specific gravity. By knowing the specific gravity of aggregates, engineers and concrete producers can adjust the mix proportions to achieve the desired density and strength of the concrete. Additionally, the specific gravity of aggregates is crucial in determining the volume and proportion of other materials, such as cement and water, in the concrete mixture. Therefore, conducting the specific gravity test using a vibration table shaker according to ASTM C29 is essential for ensuring the quality and performance of concrete.

3.3.2 Cement

In this research, the impact of the type and dosage of cement used in the construction of concrete specimens mixed and processed with drinking water or other types of water is investigated. Type 2 sulfate-resistant cement, also known as SRC (sulfate-resistant cement), with its physical and chemical specifications is in accordance with the provided Table 3-2 and ASTM standards were employed.

Table 3-2. Physical and Chemical Specifications for Type 2 Sulfate-Resistant Cement*



Chemical Requirements:	**Spec. Limit**	**Test Result**
SiO_2, (%)	^{A}	19.1
Al_2O_3, (%)	6.0 max	4.9
Fe_2O_3, (%)	6.0 max	3.6
CaO, (%)	^{A}	64.1
MgO, (%)	6.0 max	0.9
SO_3, (%) ^{C}	3.0 max	3.3
Loss on Ignition, (%)	3.5 max	3.1
Insoluble residue, (%)	1.50 max	0.42
CO_2, (%)	^{A}	1.8
Limestone, (%)	5.0 max	4.4
$CaCO_3$ in Limestone, (%)	70 min	94
Potential phase composition, (%):^{B}		
C_3S	^{A}	59
C_2S	^{A}	10
C_3A	8 max	7
C_4AF	^{A}	11
$C_3S + 4.75(C_3A)$ (%)	100 max	92

Optional Chemical Requirements	**Spec. Limit**	**Test Result**
Total Alkalies (Na2O equiv.), (%)	^{A}	0.55

Physical Requirements:	**Spec. Limit**	**Test Result**
Air content, Volume, (%)	12 max	8
Average Fineness (Blaine), (m^2/kg)	260 min 430 max	396
Autoclave Expansion, (%)	0.80 max	-0.01
Time of setting:		
Vicat Initial set, minutes	45 min 375 max	77
Compressive strengths, (Mpa)		
3 days	12.0 min	27.8
7 days	19.0 min	33.1
Compressive strengths, (psi)		
3 days	1740 min	4031
7 days	2760 min	4796
Heat of Hydration (cal/g) C1702 3 day	*D*	70
Mortar Bar Expansion ^{E} C1038-19	0.020 max	0.012

Optional Physical Requirements	**Spec. Limit**	**Test Result**
Compressive strengths, (Mpa) 28 days (March 2023)	28.0 min	40.1
Compressive strengths, (psi) 28 days (March 2023)	4060	5818

*https://mcdn.martinmarietta.com/assets/products/cement/cement-mill-certificates/midlothian-type-I-II-cert.pdf

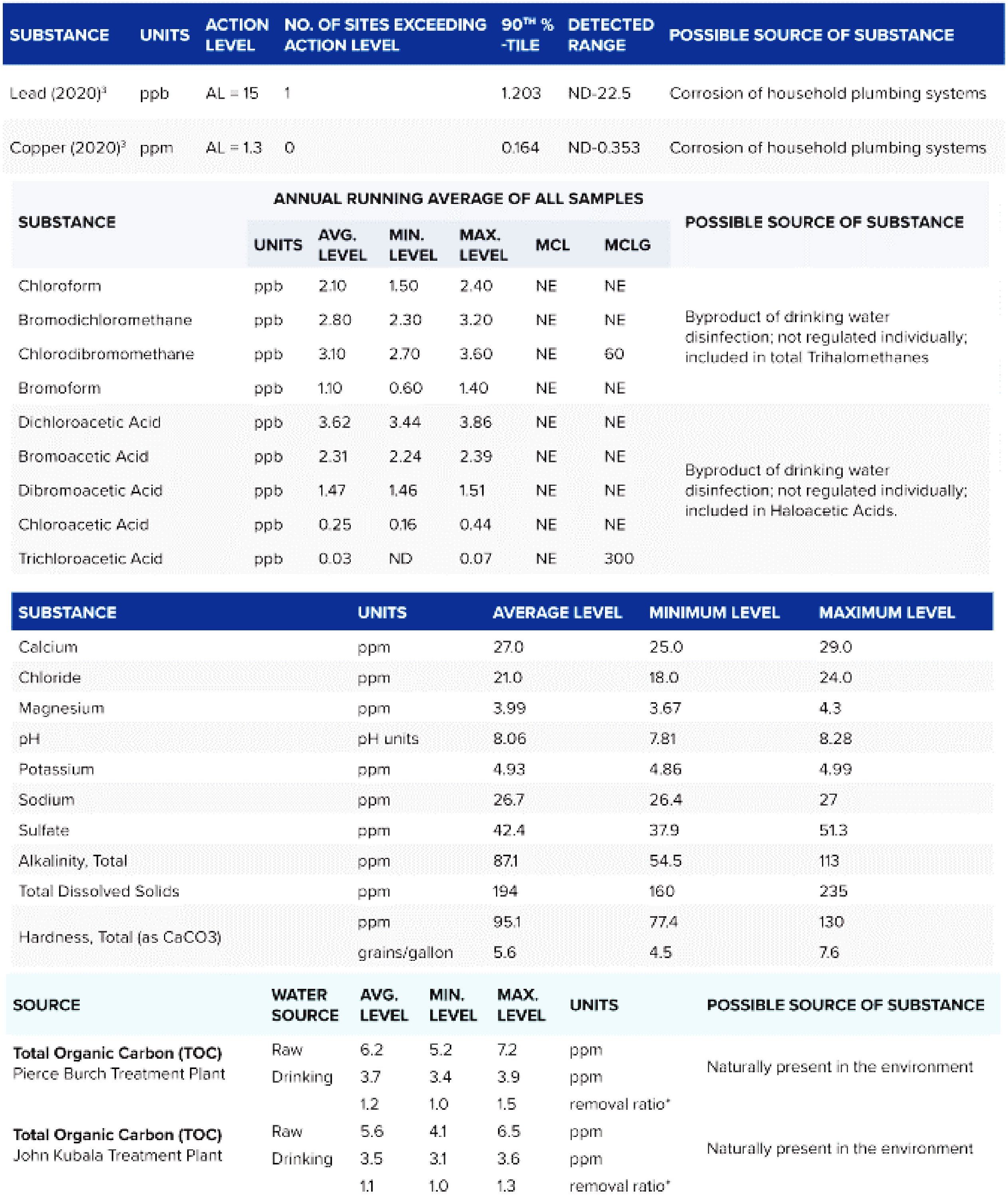
It is important to note that the cement used for specimen preparation is mixed with specific dosages of 300 and 420 kilograms per cubic meter (kg/m^3), and its influence on the strength characteristics of the resulting concrete specimens is evaluated and is illustrated in Figure 3-6.

Figure 3-6 Measuring Type I/II Cement Used in the Experiments

3.3.3 Water

For the preparation of concrete mix designs and the processing of concrete specimens, both tap water and made water were utilized. Tap water was used for the mixing and processing of concrete specimens according to the ASTM C190 standard (ASTM, 1985), and made water was also employed. The source of the water produced came from the municipal water tap located in the University of Texas at Arlington Civil Engineering Laboratory Building (CELB). To increase and decrease the pH, Potassium carbonate (K_2CO_3) was used to increase the pH, and phosphoric acid ($H_3PO_{4)}$ was used to decrease the PH. Sodium chloride (NaCl) was used for TDS.

Table 3-3 Arlington Tap Water Quality in 2022*



SUBSTANCE	UNITS	ACTION LEVEL	NO. OF SITES EXCEEDING ACTION LEVEL	90TH % -TILE	DETECTED RANGE	POSSIBLE SOURCE OF SUBSTANCE
Lead (2020)^3	ppb	AL = 15	1	1.203	ND-22.5	Corrosion of household plumbing systems
Copper (2020)^3	ppm	AL = 1.3	0	0.164	ND-0.353	Corrosion of household plumbing systems

SUBSTANCE	ANNUAL RUNNING AVERAGE OF ALL SAMPLES						POSSIBLE SOURCE OF SUBSTANCE
	UNITS	AVG. LEVEL	MIN. LEVEL	MAX. LEVEL	MCL	MCLG	
Chloroform	ppb	2.10	1.50	2.40	NE	NE	Byproduct of drinking water disinfection; not regulated individually; included in total Trihalomethanes
Bromodichloromethane	ppb	2.80	2.30	3.20	NE	NE	
Chlorodibromomethane	ppb	3.10	2.70	3.60	NE	60	
Bromoform	ppb	1.10	0.60	1.40	NE	NE	
Dichloroacetic Acid	ppb	3.62	3.44	3.86	NE	NE	Byproduct of drinking water disinfection; not regulated individually; included in Haloacetic Acids.
Bromoacetic Acid	ppb	2.31	2.24	2.39	NE	NE	
Dibromoacetic Acid	ppb	1.47	1.46	1.51	NE	NE	
Chloroacetic Acid	ppb	0.25	0.16	0.44	NE	NE	
Trichloroacetic Acid	ppb	0.03	ND	0.07	NE	300	

SUBSTANCE	UNITS	AVERAGE LEVEL	MINIMUM LEVEL	MAXIMUM LEVEL
Calcium	ppm	27.0	25.0	29.0
Chloride	ppm	21.0	18.0	24.0
Magnesium	ppm	3.99	3.67	4.3
pH	pH units	8.06	7.81	8.28
Potassium	ppm	4.93	4.86	4.99
Sodium	ppm	26.7	26.4	27
Sulfate	ppm	42.4	37.9	51.3
Alkalinity, Total	ppm	87.1	54.5	113
Total Dissolved Solids	ppm	194	160	235
Hardness, Total (as CaCO3)	ppm	95.1	77.4	130
	grains/gallon	5.6	4.5	7.6

SOURCE	WATER SOURCE	AVG. LEVEL	MIN. LEVEL	MAX. LEVEL	UNITS	POSSIBLE SOURCE OF SUBSTANCE
Total Organic Carbon (TOC) Pierce Burch Treatment Plant	Raw	6.2	5.2	7.2	ppm	Naturally present in the environment
	Drinking	3.7	3.4	3.9	ppm	
		1.2	1.0	1.5	removal ratio*	
Total Organic Carbon (TOC) John Kubala Treatment Plant	Raw	5.6	4.1	6.5	ppm	Naturally present in the environment
	Drinking	3.5	3.1	3.6	ppm	
		1.1	1.0	1.3	removal ratio*	

* https://www.arlingtontx.gov/city_hall/departments/water_utilities/knowledge_center/drinking_water_quality_question

Table 3-4 Modifications Made to Water for Sample Preparation and Curing

Waters	***TDS (ppm)***	***pH***
Control	***183***	***7.74***
Water 1	***1,000***	***8***
Water 2	***2,000***	***8***
Water 3	***3,000***	***8***
Water 4	***4,000***	***8***
Water 5	***1,000***	***6***
Water 6	***2,000***	***6***
Water 7	***3,000***	***6***
Water 8	***4,000***	***6***

The water quality analysis involved the use of two Yinmik water testers for measuring acidity, alkalinity, pH levels, and TDS in the water samples. Prior to the measurements, pH calibration was performed using buffer solutions with pH values of 9.18, 6.86, and 4.01 to ensure accurate and precise pH readings. For TDS measurements, a calibration solution with a conductivity of 1413 µS/cm was utilized to calibrate the TDS meter and establish a baseline for accurate TDS readings. These calibration procedures ensured the reliability and accuracy of the measurements, enabling a comprehensive assessment of the water quality. Material and equipment used in this study can be seen in Figure 3-7. The collected data provided valuable insights into the chemical composition and TDS levels of the water samples, aiding in the evaluation of their overall quality.

Figure 3-7 Water Testers, pH Meter, and TDS Meter

The electrical conductivity (EC) and acidity levels were precisely measured and monitored throughout the experiment. To achieve different levels of electrical conductivity in the water samples, a mixture of sea salt was used instead of sodium chloride (NaCl). The relationship between TDS in milligrams per liter (mg/l) and electrical conductivity (EC) in microsiemens per centimeter (μS/cm) was determined using the following conversion Eq.(3.4):

$$\text{TDS (mg/l)} = 640 * \text{EC } (\mu\text{S/cm}) \qquad (3.4)$$

This conversion equation allows for a comprehensive assessment of the dissolved solids content in the water samples, providing valuable insights into their TDS levels and overall quality. The accurate measurement of EC and the application of the conversion equation contributed to a thorough understanding of the water's composition and characteristics.

In the accompanying images, this dissertation showcases the setup for water preparation and the curing process. The concrete mixing water is carefully prepared in eight tanks, each identified by yellow doors. The pH meter and TDS meter are utilized to accurately measure the pH levels and TDS concentrations of water samples. The water samples are then transferred to buckets for the curing process, ensuring proper hydration and development of concrete strength. This meticulous setup guarantees precise control and measurement of water parameters, which is crucial for obtaining reliable and consistent results in the dissertation research. The process can be seen in Figure 3-8.

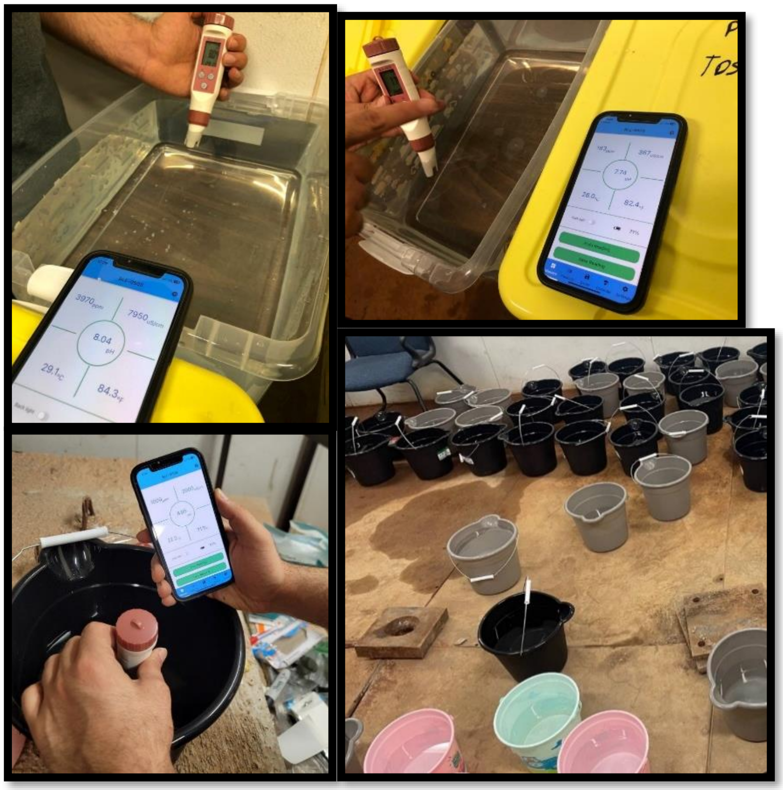


Figure 3-8 Preparation of Water Samples

3.3.3.1 Water-to-Cement Ratio (W/C)

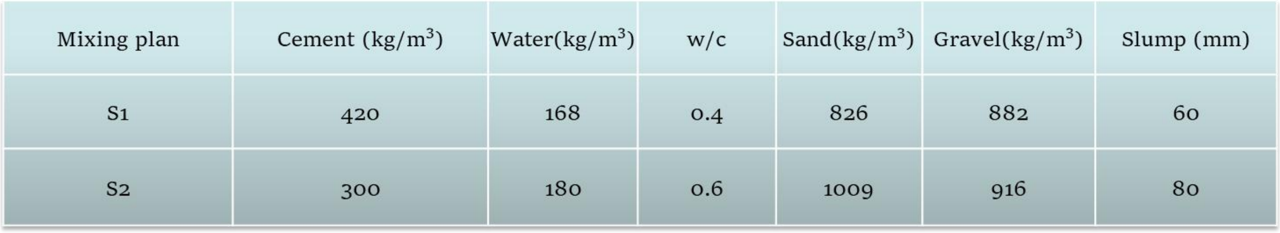
The water-to-cement ratio (W/C) plays a crucial role in the preparation of concrete mixtures and the end results of the concrete specimens made in this experiment. The aim was to maintain a consistent W/C ratio in the mixtures to ensure that any variation in this ratio does not significantly affect the obtained results. To achieve this, the W/C ratio was carefully controlled in all concrete specimens by adding water to achieve the desired workability and slump according to the ASTM C190 standard (ASTM 1995). Throughout the preparation process, the W/C ratio was maintained at fixed values of 0.4 and 0.6, following the guidelines specified in the ASTM C190 standard. This involved adding the necessary amount of water to achieve the desired consistency and slump for each concrete mixture. By adhering to the established W/C ratios, the experimental conditions were standardized, allowing for consistent comparisons and analysis of the results.

Maintaining a constant W/C ratio is essential in concrete research as it ensures the repeatability and reliability of the experiments. Controlling the water content relative to the cement content helps optimize the strength, durability, and overall performance of the concrete. The adherence to ASTM standards in determining and maintaining the W/C ratio provides a solid foundation for accurate data interpretation and meaningful conclusions.

3.3.4 Concrete Mix Design

Reputable guidelines provide valuable insights into designing concrete mixtures, emphasizing the quality of materials and recommending specific ranges for water, cement, and aggregate proportions. Considering these guidelines and the available material conditions for testing and concrete production, it is crucial to develop various mix designs to achieve an optimal and efficient concrete mixture. Therefore, several mix designs were experimentally tested in accordance with the recommendations of relevant ASTM and ACI standards to achieve an optimized mix design. Taking into account the recommendations and guidelines, this dissertation encompasses the preparation of two different mix designs. Concrete mixtures were prepared at various ages (7, 3, and 28 days) and subjected to compressive strength tests for evaluation. The results of these tests are presented in Table 3-5.

Table 3-5 Concrete Mix Designs for Prepared and Processed Concrete Samples



Mixing plan	Cement (kg/m^3)	Water(kg/m^3)	w/c	Sand(kg/m^3)	Gravel(kg/m^3)	Slump (mm)
S1	420	168	0.4	826	882	60
S2	300	180	0.6	1009	916	80

3.4 Compressive Strength Test on Concrete Samples

To accurately evaluate the structural performance of the concrete samples, it was essential to measure their compressive strengths. This parameter is a key indicator of the concrete's ability to withstand loads and determine its overall durability and suitability for structural applications. The compressive strength tests were assessed, which helped us determine its structural performance and quality.

This involved following the procedures outlined in the ASTM C192/C192M-16a standard (ASTM, 2019) for sample preparation and processing. Adhering to these guidelines ensures reliable and comparable results. Following the ASTM C192 instructions, the concrete was cast with three equal layers inside a mold. Each layer was compacted using 25 blows to eliminate any voids or air pockets. After compacting the final layer, the surface of the sample was carefully smoothed to create a uniform and level finish. Attention to details during the casting process is essential to minimize any potential variations that could affect the final compressive strength results. Notably, the temperatures varied causing the concrete samples to undergo changes and different drying conditions, especially within the initial 24 hours after casting, which significantly affected their strength development. To mitigate these effects and maintain consistent testing conditions, the concrete samples were carefully handled and stored following the recommended procedures. After the concrete mix was properly prepared, it was discharged from the mixer into designated metal molds, adhering to ASTM C143/C143M-15 standard for casting (ASTM, 2015). The molds were filled with the prepared mix, ensuring uniform distribution and adequate consolidation. To prevent moisture loss during the critical early stages, a protective plastic layer was placed on the surface of each sample. Once the concrete had sufficiently cured, the molds were carefully opened, and the samples were removed. To simulate real-world conditions and assess the long-term strength characteristics, the samples were exposed to a water basin or prepared water for the desired age periods (e.g., 3, 7, and 28 days).

This immersion period allows for hydration and further development of the concrete's strength properties. After removing the samples from the water basin, they were briefly allowed to air-dry in a controlled environment until the surface moisture evaporated. This step ensured that accurate strength measurements were obtained without interference from excess moisture on the surface. The compressive strength of the concrete samples was then determined using a specialized concrete jack testing machine. This device applies a gradually increasing load to the sample until it reaches failure, providing a precise measurement of its compressive strength. The tests were conducted in accordance with established standards and guidelines to ensure accuracy and reliability.

It is worth emphasizing that the selection of appropriate testing locations for sample preparation is crucial. The chosen locations should minimize the need for subsequent sample handling, as excessive movement or disturbance can compromise the integrity of the samples.

Additionally, suitable measures were taken to protect the samples from external factors that could affect their properties or compromise the accuracy of the test results.

By meticulously following the prescribed procedures and adhering to recognized standards for concrete compressive strength testing, the conducted tests on the prepared samples generated vital data. These results are of utmost importance in evaluating the structural capabilities and long-term durability of the concrete, ensuring the research objectives are met and enhancing the overall quality and reliability of the dissertation findings.

Figure 3-9 Preparation and Mixing of Concrete Used in Sample 0.6

Figure 3-10 Concrete Level

Figure 3-11. Compressive Strength Testing

Figure 3-12 Concrete Samples Immersed in Water for Curing

Figure 3-13 Random Photos of Lab

Figure 3-14 Water and Samples

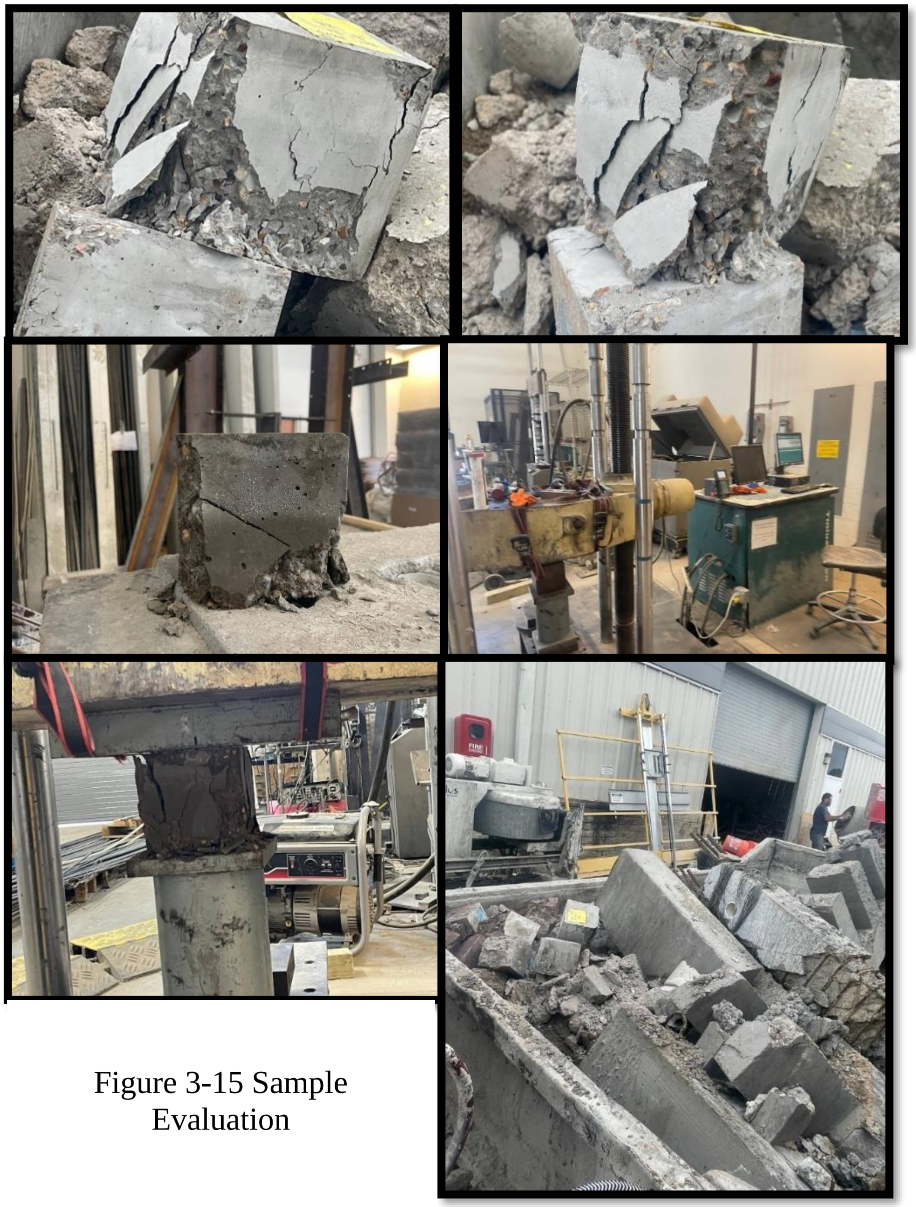


Figure 3-15 Sample Evaluation

The step-by-step process for conducting the compressive strength test of concrete is as follows and is shown in Figures 3-10 to 3-15. A detailed overview of the concrete compressive strength testing process conducted in accordance with industry standards. The process involves measuring and mixing the materials, pouring the concrete into standard molds, curing the samples, and testing their compressive strength at different time intervals. The steps outlined below ensure accuracy, reliability, and adherence to established protocols.

Step 1: Material Measurement and Mixing

Measure all materials according to two mixing plans. Follow the appropriate standards for material measurement and mixing procedures as shown in Figure 3-9. This ensures accurate and precise measurement of materials to maintain consistency. Measurements must be carried out following the relevant standards, such as ASTM C29/C29M (ASTM 2017) for coarse aggregates and the ASTM C1366-08 standard for fine aggregates (ASTM, 2019). Adhering to these standards ensures accurate proportions and quality control. Once the materials were measured, they were mixed thoroughly using the specified mixing procedures outlined in the ASTM C94-81 standard (ASTM, 2017) for ready-mixed concrete. This standard provides guidelines for achieving a uniform and consistent concrete mix, essential for obtaining reliable test results as shown Figure 3-6.

Step 2: Concrete Molding

After the concrete mixture is prepared, pour into standard molds of dimensions 15 cm ×15 cm × 15 cm. Carefully fill molds to prevent any voids or segregation within the concrete. Following the guidelines of the ASTM C192/C192M standard (ASTM, 2019), the molds must be vibrated to ensure proper compaction and to eliminate any trapped air or honeycombing, as shown in Figure 3-3.

Step 3: Demolding and Curing

Once the molds are filled, the concrete samples should be left undisturbed for a designated period. After 24 hours, the samples can be carefully removed from the molds to avoid any damage. Then, place the molds in an air pump to provide a controlled curing environment. Follow ASTM C31/C31M (ASTM 2003) for curing instructions to ensure consistency and allow the concrete to gain strength over time.

Step 4: Compressive Strength Testing

Perform compressive strength tests on the concrete specimens at three different time intervals: 3 days, 7 days, and 28 days. Follow standardized testing procedures to ensure accurate and reliable results. Utilize appropriate testing equipment, such as a compression testing machine, to measure the strength of the specimens. The compressive strength tests were performed using a calibrated compression testing machine in accordance with ASTM C39.

Step 5: Data Collection

Record the compressive strength values obtained from the testing process for each time interval. Compare the strength values with the specified requirements and industry standards.

Refer to Appendix C for additional photos showcasing the different stages of the concrete compressive strength testing process. Throughout the entire experimental procedure, strict adherence to industry standards was maintained to ensure accurate and reliable results. Some of the most used standards are:

ASTM C29/C29M-17a (2017). Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregate.

ASTM C31M-22 (2003) Standard Practice for Making and Curing Concrete Test Specimens in the Field.

ASTM C39 (2001) Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

ASTM C94-81 (2017). Standard Specification for Ready-Mixed Concrete.

ASTM C 131/C131M-20 (2020). Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine.

ASTM C136-08 (2019). Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates of Advanced Ceramics by Constant Stress-Rate Flexural Testing at Elevated Temperatures

ASTM C192/C192M-16a. (2019). Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.

These standards provide guidelines for material measurement, mixing, molding, curing, and testing procedures, ensuring consistent and comparable results. Furthermore, quality control measures were implemented at each stage of the experiment. This included verifying the compatibility of the concrete mix as per ASTM C192/192M-16a and C39, assessing uniformity (ASTM C94-81), and evaluating workability (ASTM C31-22 and C39).

These quality control measures helped to identify any deviations or inconsistencies in the concrete samples, ensuring that only reliable and representative samples were tested.

The experimental procedures used in this dissertation to assess the compressive strength of concrete were conducted with the utmost care and adherence to industry standards. The specific steps followed included:

1. Material Measurement: Accurate measurements of all ingredients, including cement, aggregates, and water were taken to ensure precise mix proportions.
2. Mixing: The materials were thoroughly mixed using a concrete mixer to achieve a uniform and consistent mixture.
3. Molding: Standard molds of 15 cm x 15 cm were used to create concrete samples of consistent dimensions.
4. Curing: The concrete samples were carefully cured for 24 hours in a controlled environment to promote proper hydration and strength development.
5. Testing: Compressive strength tests were conducted at three different time intervals of three days, seven days, and twenty-eight days.

Throughout the experimental procedure, ASTM standards were strictly followed. The use of recognized standards provides confidence in the validity of the data and allows for meaningful comparisons with other studies.

The systematic approach and meticulous execution of the experimental procedure contribute to the dissertation's credibility and validity. The results serve as a solid foundation for future research and practical applications in the field of concrete technology. Engineers and construction professionals can draw upon this dissertation 's findings to optimize concrete mix designs and ensure the reliability of concrete structures in various construction projects.

In conclusion, this dissertation's experimental procedure not only sheds light on the concrete's mechanical properties but also emphasizes the need for precise water quality control and adherence to industry standards in concrete production. The insights gained from this research contribute to advancements in construction materials and pave the way for the development of durable, sustainable, and resilient concrete structures.

CHAPTER 4: Results and Discussion

4.1 Introduction

To determine the effect of water sources on the compressive strength characteristics of concrete, as explained in the previous chapter, two mix designs were prepared and labeled as groups S1 and S2, with varying water-to-cement ratios and slump values. Additionally, the prepared concrete mixes were subjected to compressive strength testing at different ages. The following results present the compressive strength properties of the various concrete specimens, investigating the effects of total dissolved solids (TDS) and the pH of the water used in different mixing and processing scenarios, including potable water and made water.

4.2 Experimental Results and Analysis

4.2.1 Experimental Results for S1 Concrete Mix Design

Table 4-1 provides a summary of the experimental data obtained for the compressive strength tests conducted on different concrete samples at various time intervals (3 days, 7 days, and 28 days). The test samples were labeled S1 for the experiments in this section The other test samples were labeled S2, and the final batch was labeled as a control group. Table 4-1 includes information such as 1) the pH and TDS levels of water used, 2) the average force (in tons) applied during testing, and 3) dimensions of the concrete samples, and average weight (in kilograms). The S1 samples were prepared using a specific concrete mix design with a cement content of 420 kg/m^3 and a water-to-cement ratio (W/C) of 0.4.

For each time interval, the compressive strength of the concrete samples was determined by subjecting them to a compressive force using a testing machine. The force applied during testing was recorded in tons and represents the average force required to cause failure in the concrete samples. The control group represents a reference sample, which may have been prepared using a different mix design or with different water characteristics.

Table 4-1 Experimental Results for S1 Concrete Mix Design

Concrete Mix Designs	pH	TDS	Ave Force T(kg/cm^2)	Ave Force F(ton)	Dimensions (cm^3)	Ave Weight (kg)	Sample 1 Force (ton)	Sample 2 Force (ton)	Days
S1	8	1,000	200.4	45.1	15×15×15	7,854	45.56	44.65	3days
S1	8	2,000	253.3	57	15×15×15	7,984	56.33	57.68	3days
S1	8	3,000	218.7	49.2	15×15×15	7,822	50.42	48	3days
S1	8	4,000	214.7	48.3	15×15×15	7,813	48.86	47.74	3days
Control	**7.74**	**183**	**198.7**	**44.7**	**15×15×15**	**7,979**	**44.7**	**-**	**3days**
S1	6	1,000	252.9	56.9	15×15×15	7,942	56.79	57.56	3days
S1	6	2,000	262.1	59.1	15×15×15	7,830	59.04	59.15	3days
S1	6	3,000	259.1	58.3	15×15×15	7,759	58.2	58.41	3days
S1	6	4,000	246.7	55.5	15×15×15	7,753	55.56	55.44	3days
S1	8	1,000	232.9	52.4	15×15×15	7,870	52.46	52.34	**7days**
S1	8	2,000	293.3	66	15×15×15	7,935	66.83	65.17	**7days**
S1	8	3,000	256.9	57.8	15×15×15	7,873	58.45	57.15	**7days**
S1	8	4,000	248	55.8	15×15×15	7,897	55.93	55.67	**7days**
Control	**7.74**	**183**	**253.8**	**57.1**	**15×15×15**	**7,870**	**57.1**	**-**	**7days**
S1	6	1,000	304.4	68.5	15×15×15	7,895	68.38	68.62	**7days**
S1	6	2,000	316.4	71.2	15×15×15	7,871	71.992	70.408	**7days**
S1	6	3,000	299.6	67.4	15×15×15	7,855	68.67	66.13	**7days**
S1	6	4,000	293.3	66	15×15×15	7,791	66.73	65.87	**7days**
S1	8	1,000	348.9	78.5	15×15×15	7,865	79.18	77.82	28days
S1	8	2,000	391.7	89.7	15×15×15	7,954	91.95	87.71	28days
S1	8	3,000	359.6	80.9	15×15×15	7,852	82.15	79.65	28days
S1	8	4,000	345.3	77.7	15×15×15	7,846	78.48	76.92	28days
Control	**7.74**	**183**	**359.6**	**80.9**	**15×15×15**	**7,915**	**80.9**	**-**	**28days**
S1	6	1,000	384	86.4	15×15×15	7,896	88.13	84.67	28days
S1	6	2,000	420.9	94.7	15×15×15	7,847	94.88	94.52	28days
S1	6	3,000	417.3	93.9	15×15×15	7,837	94.95	93.85	28days
S1	6	4,000	409.3	92.1	15×15×15	7,821	94.83	89.46	28days

The control samples served as a benchmark for comparison with the S1 samples and they helped me evaluate the effectiveness of the specific mix design. The data presented in the table allows for the comparison of compressive strength values between different water pH and TDS levels and at different curing durations. This information helps to assess the performance of the concrete samples over time and provides insight into the effects of water quality on the strength characteristics of the concrete.

The results pertain to the compressive strength tests conducted on concrete samples produced using water mixtures based on specified compressive strength values at 3, 7, and 28-days of age. The results in Table 4-1 represent the Design S1 mix.

4.2.1.1.1 Average Compressive Strength Results and Analysis of S1 Concrete Mix Design Samples After 3-Day Curing Period

Figure 4-1 compares the results of the cured 3-day samples' compressive strength tests in a bar chart with all the pH and TDS results in text columns. The control sample's average compressive strength is 198.7. The pH 8 and TDS 183 in water are expressed in the lower text columns.

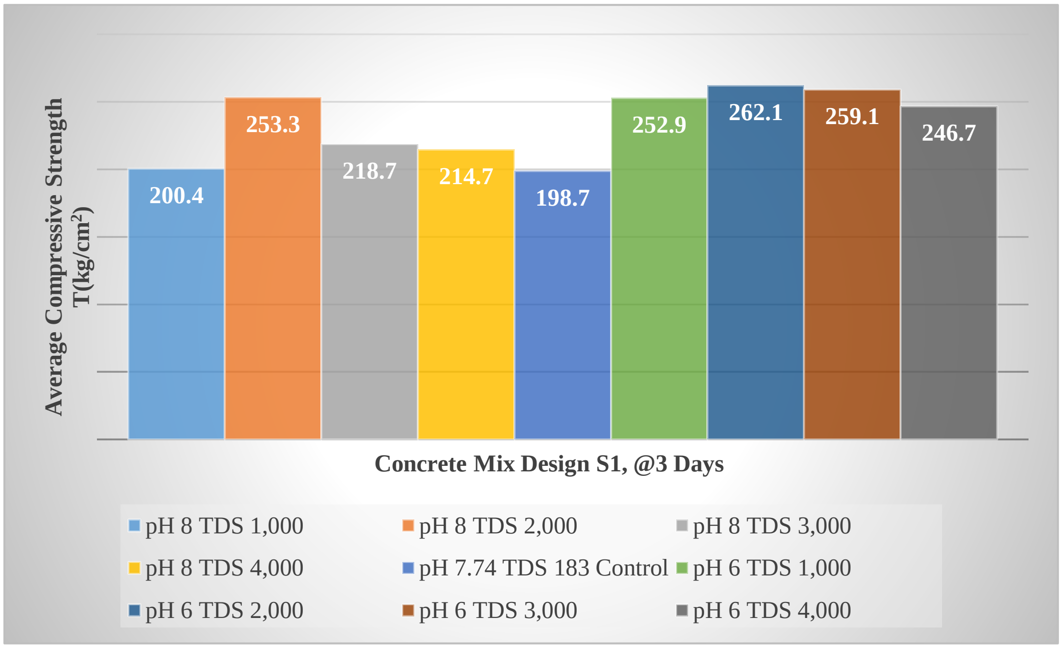


Figure 4-1 Average Compressive Strength Results in Top Bar Chart for S1 Concrete Mix Design after 3 Days of Curing with Lower Text Columns Listing pH and TDS after 3 Days of Curing

The compressive strength of the 3-day S1 concrete samples showed increased pH levels compared to the control sample (made with drinking water, also known as tap water). At pH 8 with TDS 1,000, a slight improvement in compressive strength was observed. However, pH 6 and TDS 1,000 (green column in Figure 4-1) showed an increase in compressive strength

(252.9). The highest compressive strength (262.1) can be seen in Figure 4-1’s dark blue column with pH 6 and TDS 2,000, indicating that lower TDS levels can contribute to increased compressive strength with the right pH. Notably, pH 6 with TDS 3,000 shown in the brown column, had the second highest compressive strength of 259.1.

It can be concluded that TDS 2,000 has led to an increase in compressive strength at both pH levels. The results suggest that the combination of pH and TDS levels can affect the compressive strength of the concrete samples. The findings highlight the importance of water quality, specifically pH and TDS, in determining the compressive strength of concrete. Further investigation and analysis are recommended to fully understand the underlying mechanisms and optimize the concrete mix design based on water characteristics.

4.2.1.2 Average Compressive Strength Results and S1 Concrete Mix Design Analysis after Seven-Day Curing Period

Figure 4-2 compares the seven-day average compressive strength results with pH and TDS results in water.

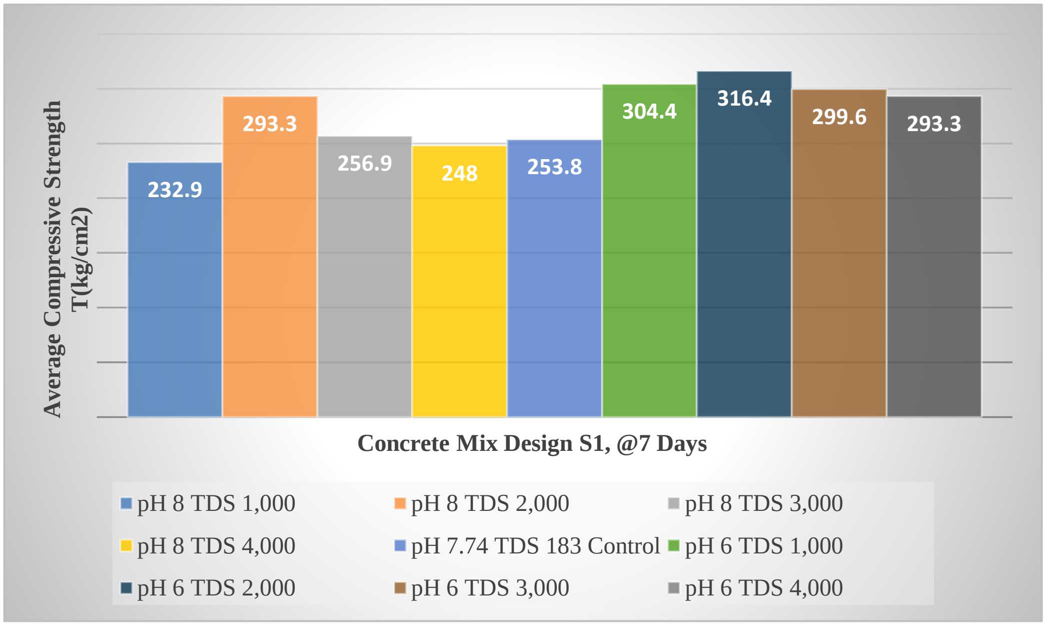


Figure 4-2 Average Compressive Strength Results in Top Bar Chart with Lower Text Columns Listing pH and TDS after 7 Days of Curing

The 7-day concrete samples were compared to the control sample (drinking water) considering variations in pH and TDS levels. The results are presented in the form of a graph, showcasing the changes in compressive strength. In the samples, an increase in compressive strength was observed at pH 8 with TDS levels of 2,000 and 3,000 were compared to the control sample. Conversely, a decrease in compressive strength was observed at TDS levels of 1,000 and 4,000. Additionally, the highest compressive strength was recorded at pH 8 with a TDS level of 2,000.Furthermore, at pH 6 all concrete samples exhibited an increase in compressive strength compared to the control sample.

It can be inferred that pH 6 had a considerable impact on the compressive strength of the samples. Notably, the highest compressive strength was observed at pH 6 with a TDS level of 2,000. It is evident that the TDS level of 2,000 positively affected compressive strength in both pH conditions. The graph visually represents the changes in compressive strength, providing a comprehensive understanding of the relationship between pH, TDS, and the mechanical properties of the concrete samples.

4.2.1.3 Average Compressive Strength Results and Analysis of S1 Concrete Mix Design Samples after 28-Day Curing Period

Results of 28-day samples compared to the control sample in terms of pH and TDS variations in water, as presented in Figure 4-3.

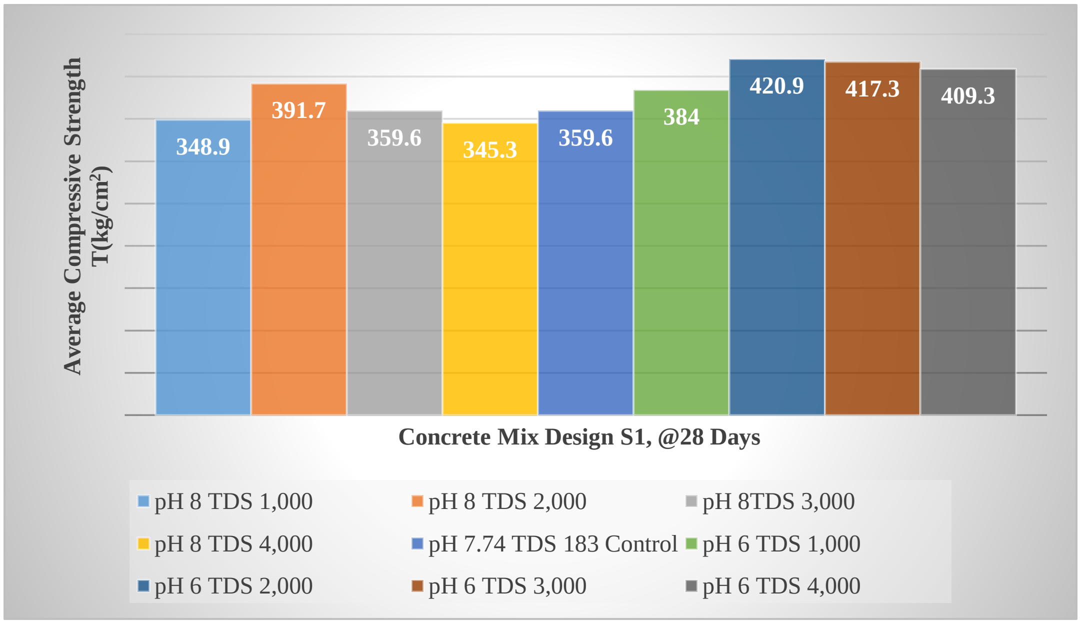


Figure 4-3 Comparison of Average Compressive Strength Results with pH and TDS after 28 Days of Curing

In the 28-days concrete samples, an increase in compressive strength was observed in pH 8 at TDS 2,000 compared to the drinking water control sample. However, a decrease in compressive strength was observed at TDS 1,000, TDS 3,000, and TDS 4,000. At pH 6, all concrete samples have gone up compared to the drinking water control sample.

It can be concluded that pH 6 had affected on the compressive strength of all the test samples. Among the pH 6 samples, the highest compressive strength was observed at TDS 2,000 based on the obtained results.

The presence of TDS 2,000 resulted in increased compressive strength in both pH levels. This indicates that TDS 2,000 has a positive effect on compressive strength.

Regression analysis was performed on our S1 Concrete Mix Design datasets with a water-to-cement ratio of 0.4 and a curing period of 28 days. The objective was to analyze the relationship between the independent variables (pH and TDS) and the dependent variable (compressive strength).

4.2.1.4 Analysis of Experimental Results for S1 Concrete Mix Designs

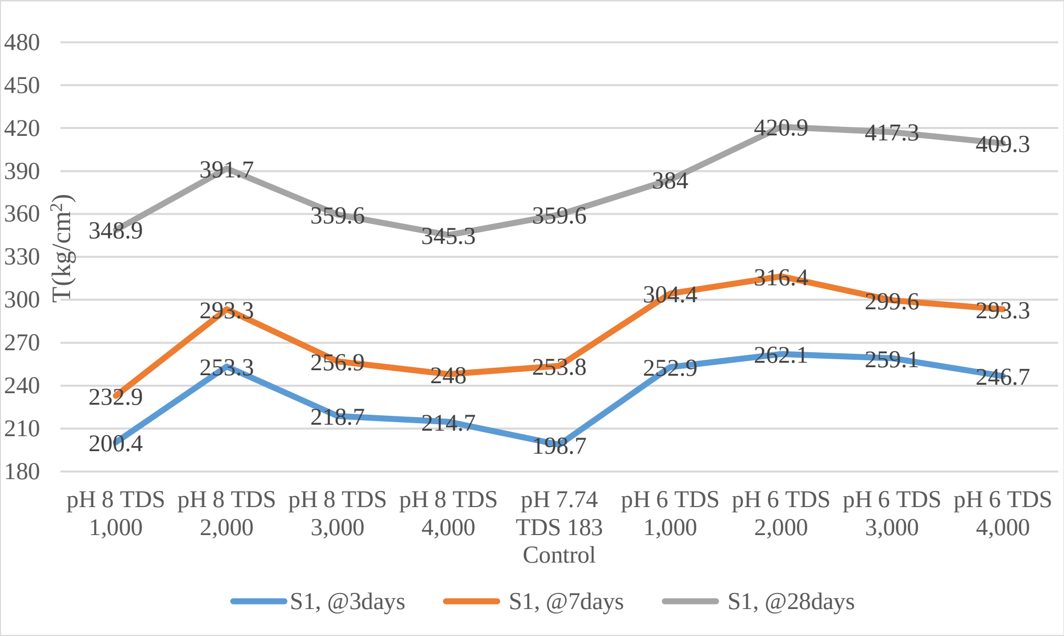


Figure 4-4 Overview of Trends in All Ages Based on S1 Obtained Graphics

S1 concrete mix designs with a water-to-cement ratio of 0.4 revealed a consistent trend across the different curing periods of 3, 7, and 28 days. The compressive strength had a similar pattern at all time points. TDS at 2,000 ppm was found to improve compressive strength under two different pH conditions as shown in Figure 4-4.

This suggests that the presence of TDS at this level has a positive impact on the overall strength of concrete samples. Furthermore, at a pH of 6, all concrete samples demonstrated an increase in compressive strength compared to the control group. This indicates that a pH of 6 positively affected the strength properties of the tested concrete.

Overall, our findings suggest that the Concrete Mix S1 Designs with a water-to-cement ratio of 0.4 exhibit consistent behavior in terms of compressive strength across different curing periods. Additionally, the presence of TDS at 2,000 ppm contributes to increased strength in specific pH conditions. Moreover, a pH of 6 shows a positive effect on the compressive strength of the concrete samples.

4.2.2 Experimental Results for S2 Concrete Mix Design

Table 4-2 data represents the results of compressive strength tests conducted on concrete samples with S2 mix designs. Samples were tested at different pH levels and TDS concentrations. The results were recorded for various curing durations. Water pH in the concrete mix ranged from 6 to 8, while TDS concentrations varied between 1,000 and 4,000. The compressive strength of concrete samples was measured using average force values expressed in kilograms per square centimeter (kg/cm^2).The concrete specimens had standardized dimensions of 15 cm × 15 cm × 15 cm, and the average weight of the specimens was also recorded. The compressive strength tests were conducted at 3 days, 7 days, and 28 days. For each combination of pH and TDS, two samples (Sample 1 and Sample 2) were tested, and the average force values were calculated. These force values indicate the compressive strength of the concrete specimens. The control column represents the compressive strength results for the control sample, which serves as a reference for comparison.

The control sample had a pH of 7.74 and a TDS of 183. The compressive strength of the control sample was evaluated at each curing duration. By analyzing the results in Table 4-2, it is possible to observe how the pH and TDS variations in the concrete mix design affect the compressive strength of the samples at different curing durations. This data provides insights into the performance and durability of the concrete under different conditions. Additionally, the S2 mix design specifies the proportions of cement, water, sand, and gravel used in concrete mixes. This information is crucial to understanding how concrete components contribute to overall compressive strength and quality. Table 4-2 provides an overview of S2 compressive strength test results, enabling a detailed analysis of concrete performance under various pH, TDS, and curing conditions.

Table 4-2 Experimental Results for S2 Concrete Mix Designs

Concrete Mix Designs	pH	TDS	Ave Force T(kg/cm^2)	Ave Force F(ton)	Dimensions (cm^3)	Ave Weight (kg)	Sample 1 Force (ton)	Sample 2 Force (ton)	Days
S2	8	1,000	125.8	28.3	15×15×15	7,754	27.98	28.62	3days
S2	8	2,000	138.2	31.1	15×15×15	7,916	30.79	31.42	3days
S2	8	3,000	137.3	30.1	15×15×15	7,940	29.48	30.71	3days
S2	8	4,000	132.4	29.8	15×15×15	7,995	29.2	30.4	3days
Control	7.74	183	101.8	22.9	15×15×15	7,747	22.9	-	3days
S2	6	1,000	130	29.3	15×15×15	7,947	28.6	30	3days
S2	6	2,000	143.6	32.3	15×15×15	7,964	31.98	32.54	3days
S2	6	3,000	138.2	31.1	15×15×15	7,899	30.54	31.65	3days
S2	6	4,000	132	29.7	15×15×15	7,912	29.5	29.9	3days
S2	8	1,000	173.8	39.1	15×15×15	7,767	37.91	40.37	7days
S2	8	2,000	172.4	38.8	15×15×15	7,983	38.41	39.67	7days
S2	8	3,000	167.1	37.6	15×15×15	7,902	37.13	38.1	7days
S2	8	4,000	157.8	35.5	15×15×15	7,887	35.45	35.55	7days
Control	7.74	183	117.3	26.4	15×15×15	7,867	26.4	-	7days
S2	6	1,000	160.9	36.2	15×15×15	7,947	36.11	36.29	7days
S2	6	2,000	184.4	41.5	15×15×15	7,953	41.23	41.76	7days
S2	6	3,000	176.9	39.8	15×15×15	7,919	39.42	40.17	7days
S2	6	4,000	162.2	36.5	15×15×15	7,914	36.14	36.86	7days
S2	8	1,000	253.3	57	15×15×15	7,816	55.97	58.02	28days
S2	8	2,000	257.8	58	15×15×15	7,865	57.42	58.58	28days
S2	8	3,000	250.2	56.3	15×15×15	7,901	55.7	56.99	28days
S2	8	4,000	248	55.8	15×15×15	7,885	55.22	56.37	28days
Control	7.74	183	237.3	53.4	15×15×15	7,774	53.4	-	28days
S2	6	1,000	246.7	55.5	15×15×15	7,938	55.22	55.77	28days
S2	6	2,000	264	59.4	15×15×15	7,974	59.08	59.71	28days
S2	6	3,000	253.8	57.1	15×15×15	7,942	56.4	57.79	28days
S2	6	4,000	241.8	54.4	15×15×15	7,909	53.43	55.46	28days

4.2.2.1 Average Compressive Strength Results for S2 Concrete Mix Design after 3-Day Curing Period

Based on variations in PH and TDS levels in the water, the results of the 3-day Concrete samples were compared with the control sample, and the findings are presented in Figure 4-5

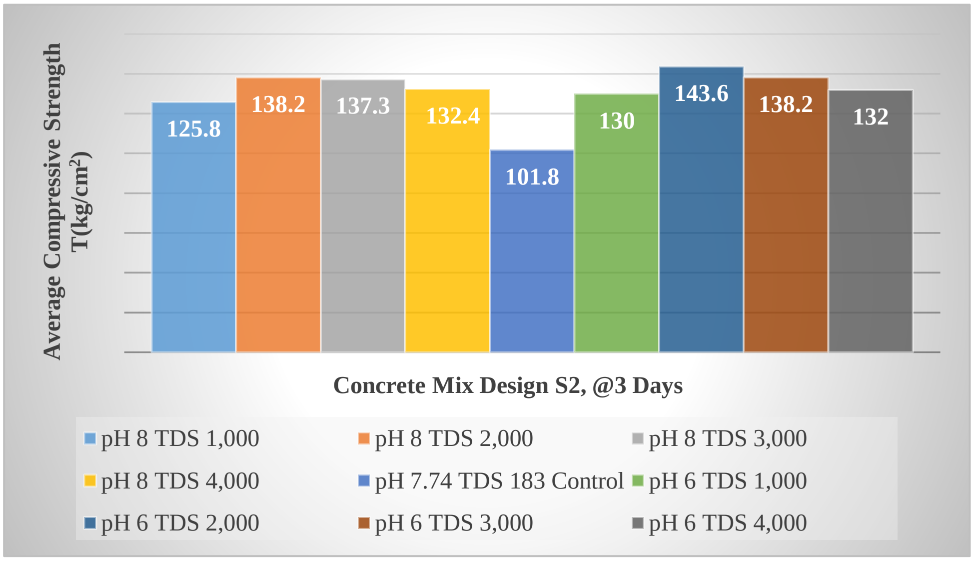


Figure 4-5 Three-Day S2 Concrete Mix Design Compressive Strength Results

Increases in compressive strength were observed in all the 3-day concrete samples, compared to the control sample (tap water). An improvement in compressive strength was particularly observed at pH 6. The results suggest that pH 6 has a notable impact on the compressive strength of the samples. Furthermore, among the tested conditions, the highest compressive strength was observed at pH 6 and TDS 2,000, although high compressive strength was also recorded at pH 8 and TDS 2,000.

Based on the variations in pH and TDS levels in the water, the results of the 7-day concrete samples were compared with the control sample, and the results are in Figure 4-6.

4.2.2.2 *S2 Concrete Mix Design Sample Analysis after 7-Day Curing Period and Compressive Strength Results*

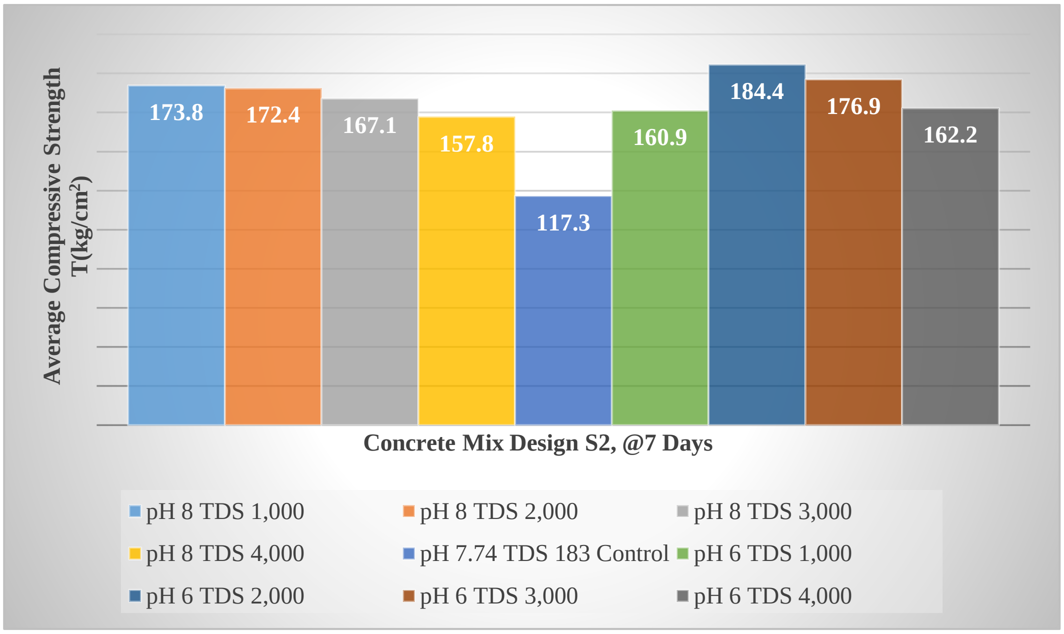


Figure 4-6 Seven-Day Comparison of Average Compressive Strength Results

The S2 Concrete Mix Design dataset showed a water-to-cement ratio of 0.6. The 7-day curing period showed all samples experiencing an increase in compressive strength compared to the control sample made with tap water. Notably, a pH of 8 had an increase in compressive strength. However, as the TDS value increased, compressive strength decreased, indicating that the water's TDS content had a negative impact on concrete’s compressive strength. Similarly, pH 6 repeated its compressive strength performance with a TDS content of 2,000, where the highest compressive strength was achieved. This indicates that pH 6 has a positive effect on compressive strength and can lead to an improved performance in the S2 concrete mix. With a TDS content of 1,000, pH 8 had the highest compressive strength, while TDS 2,000 came close to attaining the highest compressive strength. This suggests that the TDS 2,000 compressive strength is comparable to that of TDS 1,000.

Overall, the results indicate that pH and TDS in water affect concrete samples' compressive strength. Higher pH levels, particularly pH 6, have a positive impact on compressive strength. However, as the TDS content increases, the compressive strength tends to decrease. These findings emphasize the importance of considering water quality parameters when designing concrete mixtures to achieve desired strength properties.

4.2.2.3 Concrete Mix Design Sample Analysis after 28-Day Curing Period and Compressive Strength Results

Based on the variations in pH and the TDS levels in water, the 28-day concrete samples were compared with the control sample and the findings are presented in Figure 4-7.

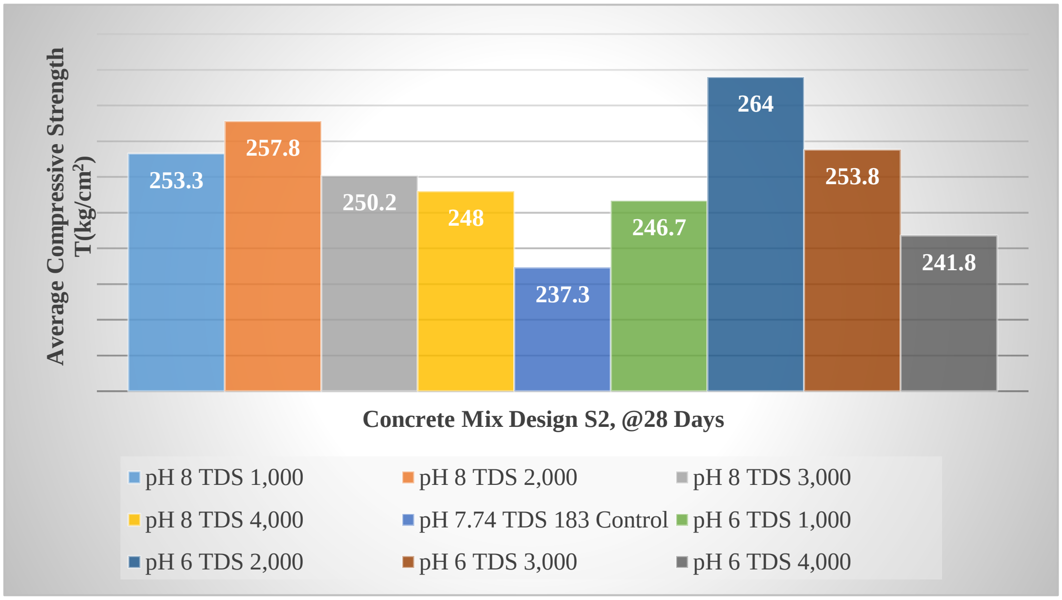


Figure 4-7 Average Compressive Strength of S2 Concrete Mix Design after 28 Days

The S2 Concrete Mix Design dataset with a water-to-cement ratio of 0.6 and a curing period of 28 days demonstrated an overall increase in compressive strength compared to the control sample. Notably, the highest compressive strength was observed at pH 6 (264) and

TDS 2,000 as well with the next highest level at pH 8 (257.8) and TDS 2,000. The findings revealed that TDS 2,000 has a positive impact on compressive strength at both pH levels.

This suggests that when a higher concentration of total dissolved solids in the water is used for the concrete mix, compressive strength is improved. Furthermore, TDS 1,000 exhibits higher compressive strength at pH 8 compared to pH 6.

4.2.2.4 Analysis of Experimental Results for S2 Concrete Mix Design

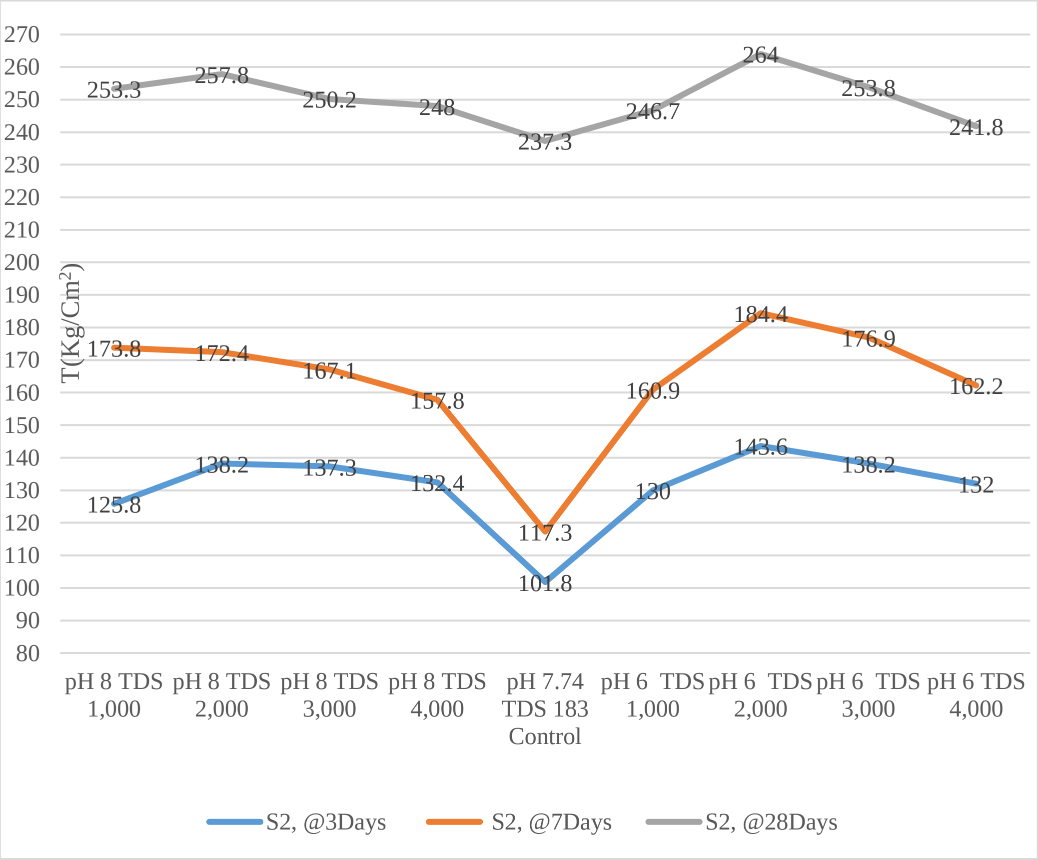


Figure 4-8 Overview of Trends in All Ages Based on Obtained Graph S2

The experiment conducted for S2 concrete mix designs with a water-to-cement ratio of 0.6 yielded consistent results across the three different curing periods of 3, 7, and 28 days. The compressive strength showed a similar trend in all three time frames (Figure 4-8). Furthermore, when the TDS level was set at 2,000, it resulted in an increase in compressive strength for two different pH levels. This suggests that TDS has a positive effect on the strength of concrete s

At pH 6, the concrete samples exhibited an increase in compressive strength, exhibiting a noticeable impact on the strength properties of the concrete mix. However, further details on the exact magnitudes of these increases are not provided in the given information.

In summary, based on the available information, the S2 concrete mix designs with a water-to-cement ratio of 0.6 demonstrated consistent trends in compressive strength across various curing periods. The TDS level of 2,000 contributed to increased compressive strength at specific pH values, and pH 6 had a positive effect on the strength of the concrete samples.

4.2.3. Comparison of Experimental Results and Analysis of S1 and S2 Concrete Mix Designs

4.2.3.1 Comparison of Test Results and Analysis of 3-Day S1 and S2 Concrete Mix Designs

Based on obtained graphs, the compressive strength profiles of the two concrete mix designs are shown Figure 4-9.

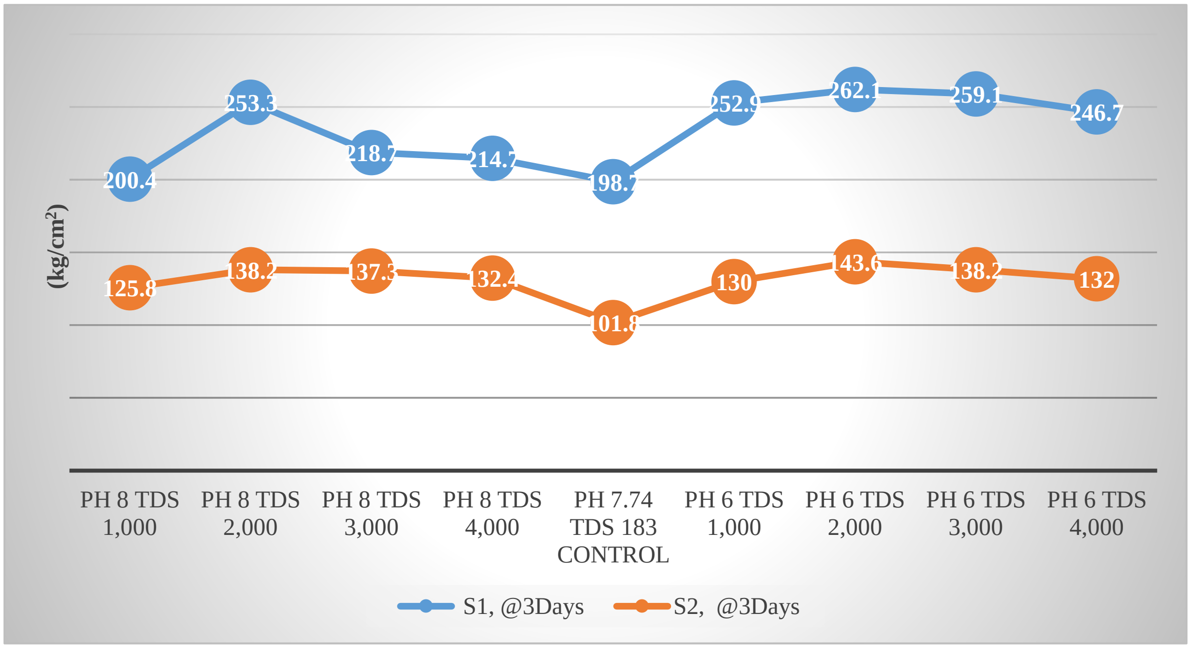


Figure 4-9 Three-Day S1 and S2 Concrete Mix Design Test Results

For the S1 concrete mix design, the compressive strength increased steadily over time for all tested durations of 3, 7 and 28 days; At pH 6, an increase in compressive strength was observed compared to the control sample (tap water). At pH 8, the highest compressive strength was achieved at TDS 2,000. The TDS level of 2,000 also resulted in increased compressive strength at pH 6.

For the S2 concrete mix design, compressive strength also experienced a consistent increase over time for all tested durations. Similar to S1, pH 6 showed a notable impact on the compressive strength, with an increase compared to the control sample. At pH 8, the highest compressive strength was observed at TDS 2,000. Additionally, TDS 1,000 demonstrated a higher compressive strength than TDS 6 at pH 8, although the compressive strength at TDS 2,000 was very close to that of TDS 1,000.

In all the tested samples, the three-day-old concrete specimens exhibited an increase in compressive strength compared to the control sample (tap water). Particularly, at pH 6 an improvement in compressive strength was observed. Furthermore, it can be noted that the concrete mix design with a water-to-cement ratio of 0.4 exhibited higher compressive strength compared to the mix design with a ratio of 0.6.

These findings indicate that at pH 6 and TDS 2,000, the highest compressive strength was achieved. Similarly, at pH 8 and TDS 2,000, the highest compressive strength was observed. Overall, these results highlight the significance of pH and TDS levels in determining the compressive strength of the concrete mixtures. The findings suggest that specific combinations of pH and TDS can improve the strength characteristics of the concrete by using tap water with pH 6 and TDS of 2,000, which showed the most favorable results.

A regression analysis was conducted to analyze the S1 (0.4) and S2 (0.6) Concrete Mix Design datasets, which had a curing period of 3 days. The objective was to investigate the relationship between the independent variables (pH, TDS, and w/c ratio) and the dependent variable (compressive strength).

Table 4-3 Three-Day S1 & S2 Concrete Mix Design Regression Analysis

Regression Statistics	
Multiple R	0.964036318
R Square	0.929366023
Adjusted R Square	0.914230171
Standard Error	16.54398552
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	50,417.5166	16,805.83887	61.40163171	2.66967E-08
Residual	14	3,831.848399	273.703457		
Total	17	54249.365			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	505.733952	36.3420501	13.9159445	1.36729E-09	427.7880068	583.6798973
pH	-10.55532414	4.053361622	-2.6040914	0.020810935	-19.24892019	-1.861728093
TDS	0.004082188	0.003072322	1.328697958	0.205198964	-0.002507287	0.010671662
w/c	-515.1666667	38.99454784	-13.2112486	2.69679E-09	-598.8016538	-431.5316796

The regression statistics an overall fit of the model. The multiple R value is 0.964 indicates a high correlation between the independent variables and the dependent variable. The coefficient of the determination is 0.929, suggesting that approximately 92.9% of the variation in the dependent variable can be explained by the independent variables.

Analyzing the coefficients Table 4-3 reveals the following relationships:

Intercept: The intercept value is 505.734, representing the estimated compressive strength when all independent variables are zero.

pH: The coefficient for pH is −10.555, suggesting that for every unit increase in pH, the compressive strength decreases by 10.555 kg/cm².

TDS: The coefficient for TDS is 0.004082, indicating that for every unit increase in TDS, the compressive strength increases by 0.004082 kg/cm².

w/c ratio: The coefficient for the w/c ratio is −515.167, implying that an increase in the water-to-cement ratio results in a decrease in compressive strength, with a reduction of 515.167 kg/cm².

The Eq. (4.1) based on this analysis is:

$$\text{Compressive Strength} = 505.734 - 10.555 * \text{pH} + 0.004082 * \text{TDS} - 515.167 * \text{w/c} \quad (4.1)$$

The calculated relationships are specifically connected to the concrete mix designs dataset and the given range of values for pH, TDS, and the w/c ratio. Further validation and analysis are recommended to evaluate the applicability of these equations to different datasets and conditions.

In conclusion, the regression analysis provides valuable insights into the relationship between pH, TDS, the w/c ratio, and compressive strength in the concrete mix designs S1 (0.4) and S2 (0.6) samples for a curing period of three days. The derived equations can serve as predictive tools for estimating compressive strength based on the provided independent variables.

4.2.3.2 Test Results and Analysis of Two Concrete Mix Designs: S1 and S2 at 7 Days

Based on the obtained graphs, the compressive strength profiles of the two concrete mix designs are shown in Figure 4-10.

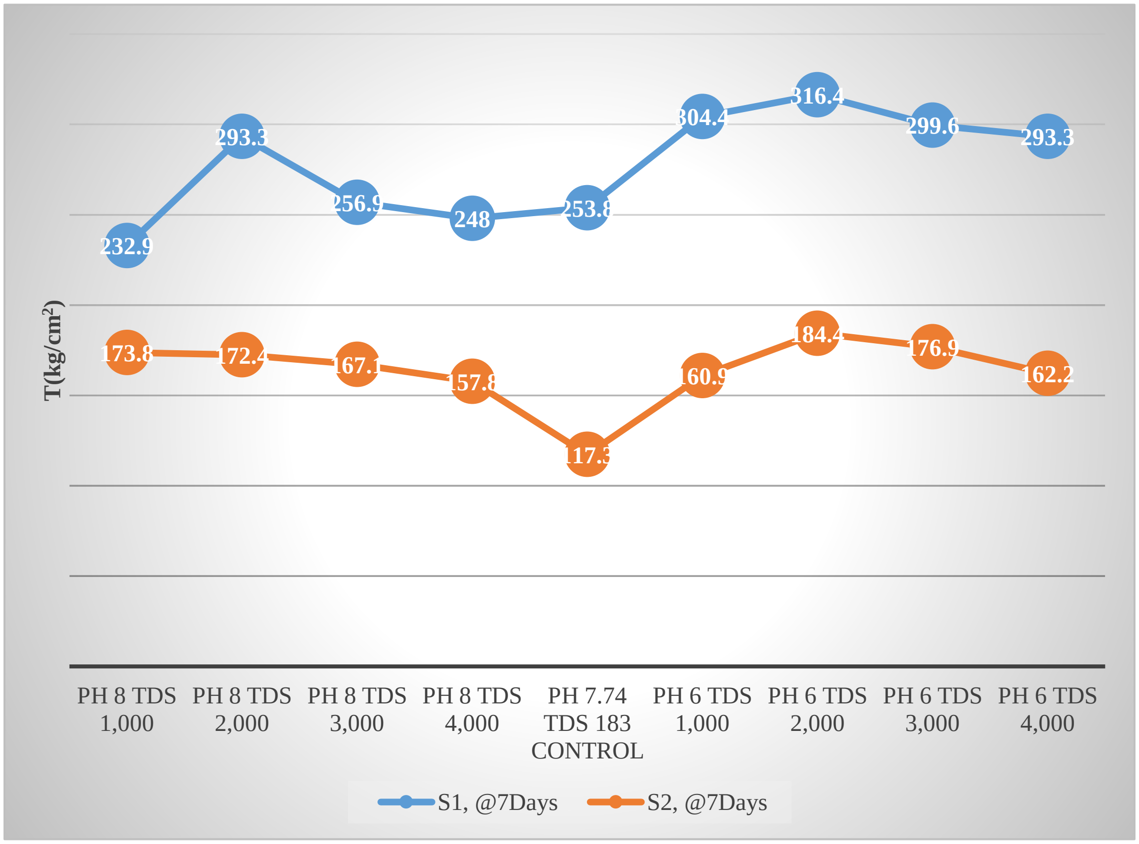


Figure 4-10 Results for S1 and S2 at Seven Days

In all the concrete samples tested, after a curing period of seven days, an increase in compressive strength was observed and compared to the reference water sample, except in the case of pH 8 at TDS 4,000.Improvement in compressive strength was observed at pH 6. Additionally, the mix design with a water-to-cement ratio of 0.4 exhibits higher compressive strength compared to the mix design with a ratio of 0.6.

The results indicate that both pH and TDS affect the compressive strength of concrete samples. Specifically, the highest compressive strength is achieved at pH 6 and TDS 2,000. Similarly, at pH 8, the highest compressive strength is observed at TDS 1,000. However, it is worth noting that the compressive strength at TDS 2,000 is very close to the compressive strength at TDS 1,000.

Based on these findings, it can be concluded that pH and TDS have an impact on the compressive strength of the concrete samples. Controlling and optimizing the pH and TDS levels in the concrete mix designs can lead to improved compressive strength properties. The mix design with a water-to-cement ratio of 0.4 shows better performance in terms of compressive strength compared to the mix design with a ratio of 0.6.

The regression analysis was conducted on data from concrete mix designs S1 (0.4) and S2 (0.6) after curing for Seven days. The analysis focuses on presenting an advanced understanding of the relationship between independent variables (pH, TDS, and water-to-cement ratio) and an dependent variable (compressive strength).

Table 4-4 Regression Analysis of Concrete Mix Designs S1 & S2 after 7 Days of Curing

Regression Statistics	
Multiple R	0.953095086
R Square	0.908390243
Adjusted R Square	0.888759581
Standard Error	21.17443891
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	62241.86	20747.28797	46.27405015	1.63178E-07
Residual	14	6276.996	448.3568632		
Total	17	68518.86			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	600.616995	46.51373	12.91268107	3.6303E-09	500.8549604	700.3790296
pH	-14.17312799	5.187847	-2.731986747	0.016207973	-25.29995219	-3.046303796
TDS	0.002380331	0.003932	0.605339366	0.554640125	-0.006053455	0.010814117
w/c	-569.8888889	49.90863	-11.41864395	1.76455E-08	-676.9322566	-462.8455212

The regression statistics that the model's fit is quite strong. The multiple R value of 0.9531 indicates a high correlation between the independent variables and the dependent variable. The coefficient of determination (R^2) is 0.9084, indicating that approximately 90.84% of the variation in the dependent variable can be explained by the independent variables. The adjusted coefficient of determination value of 0.8888 suggests that the model is a good fit and avoids overfitting. The standard error of the regression is 21.1744, representing the average deviation of the observed values from the regression line. The ANOVA Table 4-4 tests the significance of the regression model. The F-statistic of 46.2741 with a p-value of 1.63178E-07 indicates that the overall regression model is statistically. This implies that the independent variables (pH, TDS, and water-to-cement ratio) collectively have an impact on the compressive strength of the concrete samples.

Looking at the coefficients in Table 4-4, the intercept value is 600.617, representing the estimated compressive strength when the pH, TDS, and water-to-cement ratio are all zero. The coefficients for pH, TDS, and the water-to-cement ratio are −14.1731, 0.0024, and − 569.8889, respectively. These coefficients represent the change in compressive strength associated with a one-unit change in each respective independent variable, holding other variables constant.

The Eq. (4.2) based on this analysis is:

$$\text{Compressive Strength} = 600.617 - 14.1731 * \text{pH} + 0.0024 * \text{TDS} - 569.8889 * \text{w/c} \quad (4.2)$$

where:

Compressive Strength represents the predicted compressive strength in kg/cm² unit.

pH represents the pH value of the concrete mix.

TDS represents the total dissolved solids in the water.

Water-to-cement ratio represents the ratio of water to cement in the mix design.

Based on these findings, it can be concluded that both pH and TDS (total dissolved solids) have an impact on the compressive strength of the concrete samples. The experimental results indicate that higher pH levels (pH 8) generally result in higher compressive strengths compared to lower pH levels (pH 6) for both mix designs (S1 and S2). Additionally, the increase in TDS levels (ranging from 1,000 to 4,000) has a slight but noticeable impact on the compressive strength of the concrete, with higher TDS levels generally correlating with lower strengths.

4.2.3.3 Comparison of Experimental Results and Analysis for Two Concrete Mix Designs: S1 and S2 at 28 Days

Based on the obtained graphs, the compressive strength profiles of the two concrete mix designs are shown in Figure 4-11:

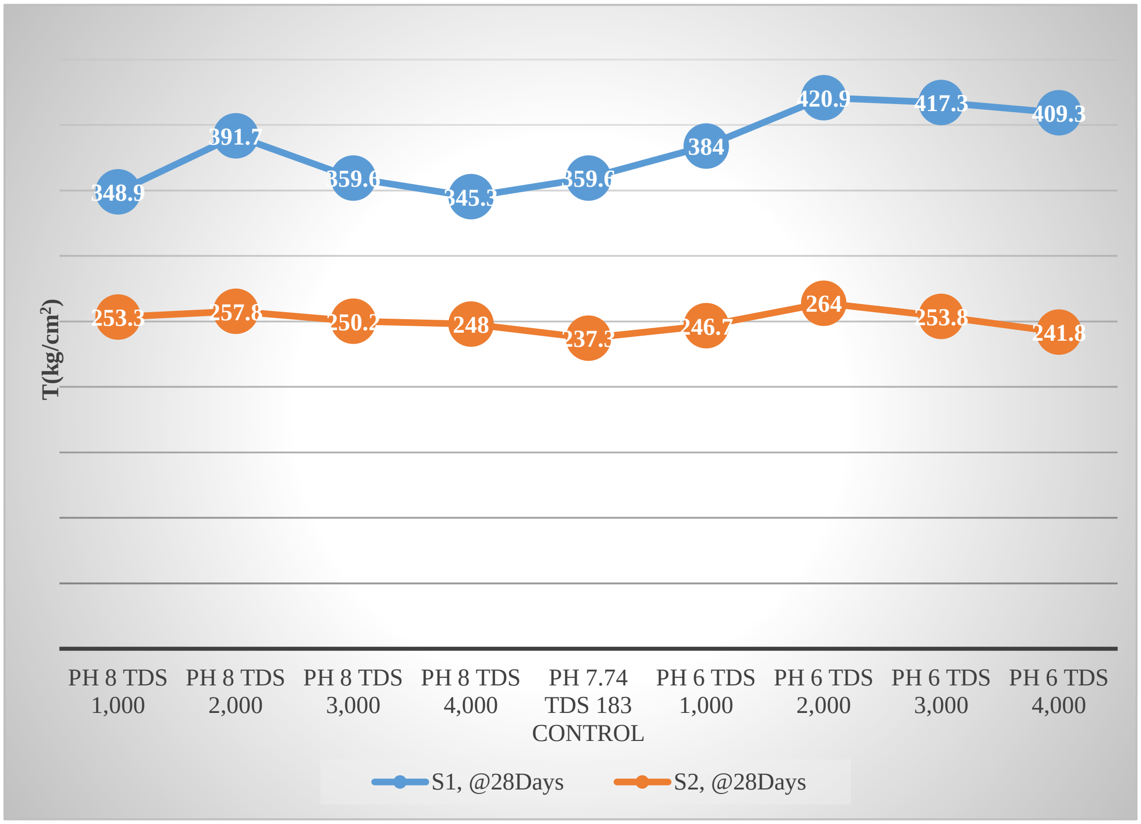


Figure 4-11 Results for S1 and S2 at 28 Days

In all samples, the 28-day concrete exhibited an increase in compressive strength compared to the water reference (control) sample. Increases in compressive strength were observed at pH 6. Furthermore, the concrete mixture with a water-to-cement ratio of 0.4 exhibited higher compressive strength than the mixture with a ratio of 0.6. It can be concluded that pH and TDS have an impact on the compressive strength of concrete samples. Based on the obtained results, the highest compressive strength was observed at pH 6 with a TDS of 2,000. Additionally, at pH 8, the highest compressive strength was observed with a TDS of 2,000.

The regression analysis of the concrete mix designs dataset for S1 (0.4) and S2 (0.6) with a curing period of 28 days indicates a strong relationship between the independent variables (pH, TDS, and w/c) and the dependent variable (compressive strength).

Table 4-5 Regression Analysis of Concrete Mix Designs S1 & S2 at 28 days

Regression Statistics	
Multiple R	0.970555888
R Square	0.941978731
Adjusted R Square	0.929545602
Standard Error	18.81462909
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	80,458.74125	26,819.58042	75.76360949	6.77661E-09
Residual	14	4,955.86375	353.9902679		
Total	17	85,414.605			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	727.9339251	41.32995595	17.61274379	5.97886E-11	639.2899858	816.5778645
pH	-12.10436459	4.609680986	-2.625857326	0.019946918	-21.991147	-2.217582174
TDS	0.001195406	0.003493994	0.342131532	0.737333698	-0.006298467	0.008689278
w/c	-657.6111111	44.34650605	-14.82892723	5.92297E-10	-752.724907	-562.4973153

The multiple R value of 0.9706 suggests a high correlation between the independent variables and the dependent variable. The coefficient of determination is 0.942, indicating that approximately 94.2% of the variation in the dependent variable can be explained by the independent variables. The adjusted coefficient of determination value of 0.9295 further confirms the good fit of the model.

The standard error of the regression is 18.8146, representing the average deviation of the observed values from the regression line. This value indicates the precision of the model's predictions.

ANOVA Table 4-5 tests the significance of the regression model. The F-statistic of 75.7636 with a p-value of 6.77661E-09 suggests that the overall regression model is statistically, indicating that the independent variables (pH, TDS, and w/c) affected the compressive strength of the concrete samples.

Looking at coefficients Table 4-5, the intercept value is 727.9339, representing the estimated compressive strength when all independent variables are zero. The coefficients for pH, TDS, and w/c are −12.1044, 0.0012, and −657.6111, respectively. These coefficients indicate the change in compressive strength for each unit change in the corresponding independent variable, holding other variables constant.

The Eq. (4.3) based on this analysis is:

$$\text{Compressive Strength} = 727.9339 - 12.1044 * \text{pH} + 0.0012 * \text{TDS} - 657.6111 * \text{w/c} \qquad (4.3)$$

Please note that the equation is based on the specific conditions of the concrete mix designs dataset and the given regression analysis. The units for the compressive strength in this equation are kg/cm^2.

4.3 Comparative Analysis of Concrete Mix Designs

S1 and S2 Made of Water at Various Ages

Based on the obtained charts, the compressive strength profiles of the two concrete mix designs can be seen in Figure 4-12:

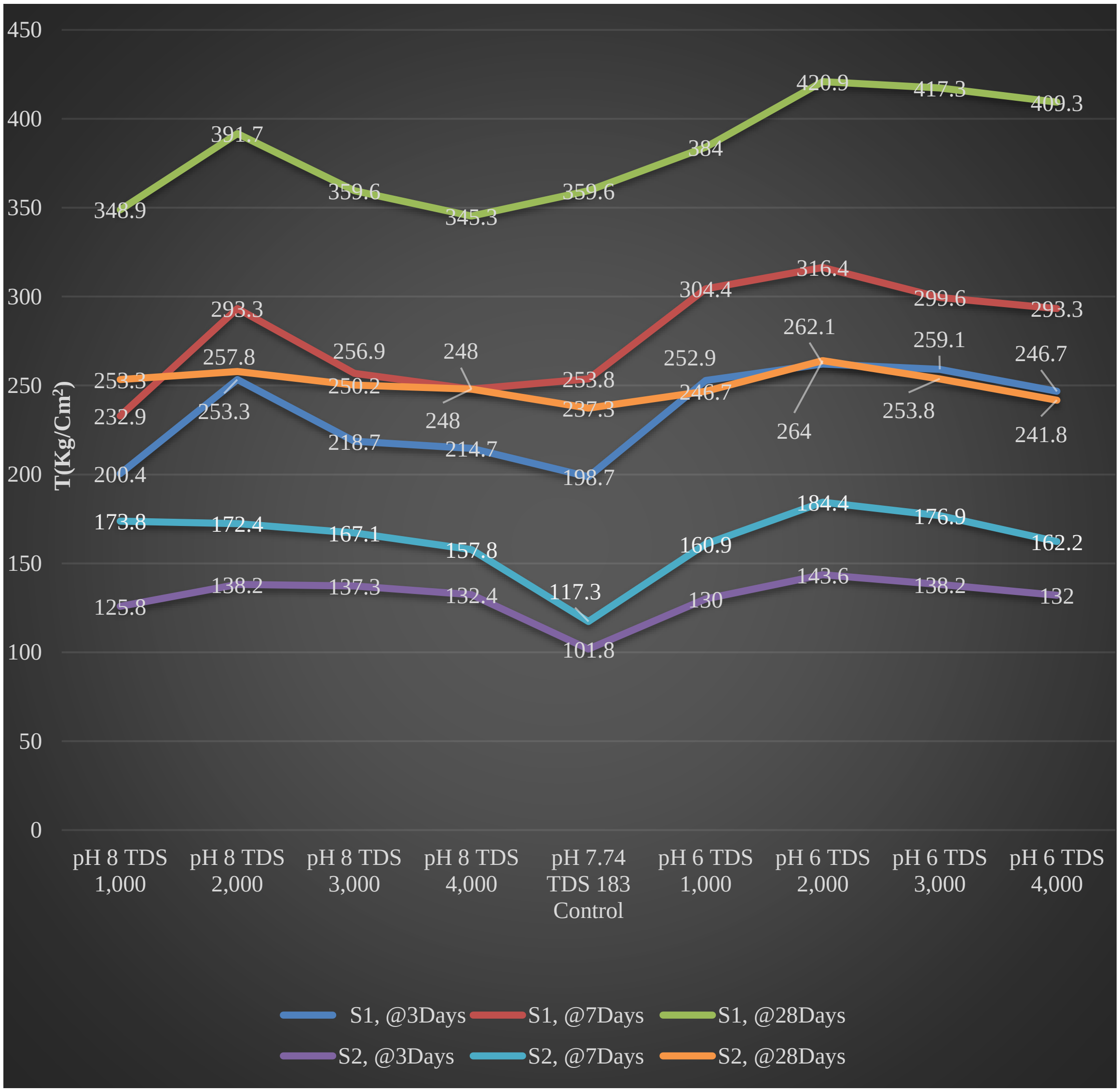


Figure 4-12 Results for S1 and S2 at All Ages

The test results for the concrete mix designs with water-to-cement ratios of 0.4 and 0.6 have shown a similar trend in compressive strength across all curing ages (7, 3, and 28 days).

2,000 TDS (Total Dissolved Solids) led to an increase in compressive strength at both pH levels. Specifically at pH 6., the concrete samples exhibited an improvement in compressive strength.

4.3.1 Regression Analysis Results for Concrete Mix Designs with w/c Ratios of 0.6 and 0.4

Table 4-6 Regression Analysis Results for Concrete Mix Designs with w/c Ratios of 0.6 and 0.4

Regression Statistics	
Multiple R	0.973157247
R Square	0.947035027
Adjusted R Square	0.942711356
Standard Error	20.22785951
Observations	54

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	358,486.8446	8,9621.71115	219.034928	1.32307E-30
Residual	49	20,049.14872	409.1663005		
Total	53	378,535.9933			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	547.0985207	25.85054176	21.16390929	2.67436E-26	495.1499122	599.0471293
pH	-12.27760557	2.861307354	-4.290907635	8.35326E-05	-18.02761798	-6.527593169
TDS	0.002552641	0.002168782	1.176993242	0.244884027	-0.001805689	0.006910972
Days	5.078666051	0.251050259	20.22967862	1.95523E-25	4.574161668	5.583170434
w/c	-580.8888889	27.52663022	-21.10279697	3.03943E-26	-636.2057233	-525.5720544

The purpose of this regression analysis was to investigate the relationship between several factors and the compressive strength of concrete mix designs with water-to-cement (w/c) ratios of 0.6 and 0.4. The analysis focuses on providing insights into how these factors affect the compressive strength at different ages (28, 7, and 3 days).

The statistical results obtained from the analysis are as in Table 4-6:

- Multiple R: 0.973157247
- R^2: 0.947035027
- Adjusted Coefficient of Determination: 0.942711356
- Standard Error: 20.22785951
- Observations: 54

The analysis of variance (ANOVA) revealed that the regression model was predicted compressive strength of both mix designs ($p < 0.001$). This suggests that the independent variables included in the analysis have an impact on compressive strength.

The coefficients derived from the regression analysis provide insights into the relationship between the independent variables and compressive strength. The intercept value of 547.0985207 represents the estimated compressive strength when all independent variables are set to zero. The coefficients for pH, TDS, Days, and w/c represent the estimated effect of each variable on the compressive strength.

To calculate the compressive strength in kg/cm^2, the following Eq. (4.4) can be used:

$$\text{Compressive Strength} = 547.0985207 - 12.27760557 * pH + 0.002552641 * TDS + 5.078666051 * Days - 580.8888889 * w/c \tag{4.4}$$

The results indicate that pH, TDS, the number of curing days, and the w/c ratio affect compressive strength. By manipulating these variables within the specified mix designs, engineers and researchers can optimize the compressive strength of the concrete.

The R^2 value of 0.947035027 indicates that approximately 94.7% of the variation in the compressive strength can be explained by the independent variables included in the regression model. This suggests a strong relationship between the selected factors and the compressive strength. It is worth noting that the standard error of 20.22785951 represents the average deviation between the actual and predicted compressive strengths. This indicates the accuracy of the regression model in estimating the compressive strength values.

Overall, these findings provide insights into the relationship between pH, TDS, days concrete spent curing, w/c ratio, and the compressive strength of concrete mix designs with different w/c ratios at various ages. They can serve as a basis for optimizing the mix designs and enhancing the overall quality and performance of concrete structures.

4.4 Discussion of Results

Based on the laboratory experiments and studies conducted in this research, the overall results can be summarized as follows:

In all samples of 3-day concrete mix designs (S1), an increase in compressive strength was observed compared to the control sample (drinking water) at pH 8, with a slight effect observed at TDS 1,000. However, at pH 6 and TDS 1,000, an increase in compressive strength was observed. It can be concluded that pH 6 has a positive effect on the compressive strength of the samples. Furthermore, the highest compressive strength was observed at pH 6 and TDS 2,000. Similarly, the highest compressive strength was observed at pH 8 and TDS 2,000. TDS 2,000 has led to an increase in compressive strength at both pH levels.

In the 7-day concrete mix designs (S1), an increase in compressive strength was observed at pH 8 and TDS 2,000 and TDS 3,000, while a decrease was observed at TDS 1,000 and TDS 4,000 compared to the control sample. Additionally, the highest compressive strength was observed at pH 8 and TDS 2,000.

In all samples of 7-day concrete mix designs (S1) at pH 6, an increase in compressive strength was observed compared to the control sample. Furthermore, pH 6 has an effect on the compressive strength of the samples. The highest compressive strength was observed at pH 6 and TDS 2,000. TDS 2,000 has led to an increase in compressive strength at both pH levels. In 28-day concrete mix designs (S1), an increase in compressive strength was observed at pH 8 and TDS 2,000, while a decrease was observed at TDS 1,000, TDS 3,000, and TDS 4,000 is compared to the control sample. Furthermore, the highest compressive strength was observed at pH 8 and TDS 2,000.

In all samples of the 28-day concrete mix designs (S1) at pH 6 , an increase in compressive strength was observed compared to the control sample. Furthermore, pH 6 has an influence on the compressive strength of the samples. The highest compressive strength was observed at pH 6 and TDS 2,000. TDS 2,000 led to an increase in compressive strength at both pH levels. The results of the experiments in mix designs with a water-to-cement ratio of 0.4 (S1) indicate a relatively consistent trend during all the curing durations (7, 3, and 28 days). TDS 2,000 led to an increase in compressive strength at both pH levels. Samples with a water-to-cement ratio of 0.4 (S1) at pH 6 showed an increase in compressive strength.

In all samples of 3-day concrete mix designs (S2), an increase in compressive strength was observed compared to the control sample at pH 6, with an increase in compressive strength. Furthermore, pH 6 has an effect on the compressive strength of the samples. The highest compressive strength was observed at pH 6.2 with TDS 2,000, as well as at pH 8 with TDS 2,000.

In all samples of 7-day concrete mix designs (S2), an increase in compressive strength was observed compared to the control sample at pH 8, accompanied by an increase in compressive strength. However, the compressive strength decreased with increasing TDS, and pH 6 exhibited similar behavior in its effect on the compressive strength of the samples. The highest compressive strength was observed at pH 6 and TDS 2,000, as well as at pH 8 and TDS 1,000, although the compressive strength in TDS 2,000 was very close to that in TDS 1,000. In all samples of 28-day concrete mix designs (S2), an increase in compressive strength was observed compared to the control sample, and at pH 6, an increase in compressive strength was observed. Furthermore, the compressive strength was higher in mix designs with a water-to-cement ratio of 0.4 compared to 0.6. It can be concluded that pH and TDS have an effect on the compressive strength of the samples. The highest compressive strength was observed at pH 6 and TDS 2,000, as well as at pH 8 and TDS 2,000.

The results of the experiments in mix designs with a water-to-cement ratio of 0.6 (S2) indicate a relatively consistent trend in all ages (7, 3, and 28 days). TDS 2,000 has led to an increase in compressive strength at both pH levels. Samples with a water-to-cement ratio of 0.6 (S2) at pH 6 showed an increase in compressive strength.

These results provide insights into the effects of pH and TDS on the compressive strength of concrete mix designs at different ages and water-to-cement ratios. The findings can be utilized to optimize the design and production of concrete with desired strength characteristics.

4.5 Practical Applications

The findings from the compressive strength tests and analysis of concrete mix designs presented in this dissertation have several specific and practical applications in the field of construction and civil engineering:

- Optimizing Concrete Mix Design: The results provide insights into the influence of pH and total dissolved solids (TDS) on the compressive strength of concrete. Engineers can utilize this information to optimize the proportion of cement, aggregates and water for specific construction projects. For instance, in projects where high compressive strength is required, a higher pH level (pH 8) can be chosen, along with a suitable TDS level (TDS 2,000), to achieve enhanced concrete strength.
- Enhancing Quality Control and Assurance: Compressive strength tests serve as essential quality control measures for concrete production. Construction companies and project managers can closely monitor the strength characteristics of concrete samples at different curing durations. By comparing the actual compressive strength with the design specifications, they can ensure that the produced concrete meets the required performance standards, preventing potential structural issues and ensuring the longevity of the constructed elements.
- Assessing Concrete Performance in Different Environments: The obtained compressive strength data facilitates the evaluation of concrete performance under varying environmental conditions. Engineers and researchers can analyze the influence of pH 6 and TDS 2,000 based on the strength properties of concrete in specific locations or exposure conditions. This assessment allows them to select appropriate concrete mix

designs for different projects based on the anticipated environmental challenges, ensuring long-term durability and reliability of the structures.

- Customizing Concrete Mixes for Challenging Environments: The knowledge gained from this dissertation can be applied to optimize concrete mix designs for environments with specific pH and TDS conditions. For example, in coastal regions where concrete is exposed to harsh marine environments and high chloride levels, engineers can adjust the mix design based on their findings. Incorporating suitable additives or supplementary cementitious materials can enhance the concrete's resistance to chloride-induced corrosion and improve its overall durability.
- Promoting Sustainable Concrete Production: Research results from this dissertation contribute to the development of sustainable concrete production practices. By identifying the optimal mix design parameters, such as pH and TDS, concrete producers can minimize waste and reduce the consumption of natural resources, leading to more environmentally-friendly concrete production. Additionally, utilizing locally available materials and optimizing mix designs can further enhance the sustainability of concrete production processes.
- Guideline Development for Concrete Mix Design: Lessons obtained from the results of this research can serve as a foundation for developing guidelines and standards for concrete mix design. Engineers and practitioners can refer to these guidelines when designing concrete mixes for specific applications, considering the effect of pH 6 and TDS 2,000 for a better compressive strength in concrete. These guidelines can aid in

standardizing concrete mix design practices, ensuring consistent and performance of concrete structures.

In summary, the practical applications of the dissertation 's findings include optimizing concrete mix designs for specific project requirements, enhancing quality control and assurance in concrete production, evaluating concrete performance under various environmental conditions, customizing mixes for challenging environments, promoting sustainable concrete production practices, and providing guidelines for concrete mix design.

Chapter 5: Results and Recommendations

5.1 Key Findings Based on Most Relevant Literature Reviews

This dissertation benefited greatly from the knowledge of those who are still establishing the foundation of this dissertation. Concrete production methods are constantly changing. The emphasis in this dissertation is on how to improve compressive strength of concrete by determining the best combination of pH and total dissolved solids. When viewing this research that preceded this dissertation, it is observed that the search for the best concrete water mixture is an ongoing process. Researchers are still finding ways to improve concrete mixtures, and potable water is still the most common water used in the process.

Recognizing major breakthroughs designed to improve concrete mixture water is essential for anyone working in the concrete construction industry. The pH and TDS approach to solving concrete water problems in concrete production was selected because it is not a publicized current solution in the industry, which makes this dissertation one of the breakthroughs needed to continue the ongoing efforts to improve concrete strength.

1. **Effect of Salt Water on Compressive Strength of Concrete** (Tiwari et al, 2014):

   *Key Finding***:** No reduction in strength occurred when using saltwater for casting and curing concrete.

   *Comparison***:** This suggests that the salts or pH levels inherent in saltwater do not reduce compressive strength. This dissertation further emphasizes the importance of pH, wherein higher pH levels (closer to that of seawater) led to better compressive strengths.

2. **Effect of pH on Compressive Strength of Concrete** (Akomah et al, 2018):

Key Finding: Water sources with higher acidity, like aquarium water and Amissano well water, resulted in lower concrete strength.

Comparison: The key finding here aligns with this dissertation's results, which show that concrete mixed with higher pH levels (lower acidity) have better compressive strength.

3. **Effect of Different pH Waters on Compressive Strength & Tensile Strength of Concrete** (Gudipudi et al, 2020)

   Key Finding: By Day 28, there was a slight increase in strength at pH levels 4 and 9.

   Comparison: This suggests that extreme pH levels can influence concrete strength over time. This dissertation consistently observed better strength at pH 8, reaffirming the significance of pH on concrete strength.

4. **Effect of Water-Cement Ratio on Mix Design and Mechanical Strength of Copper Slag Aggregate Concrete** (Panda et al., 2020)

   Key Finding: Copper slag in concrete improves mechanical strength, and due to its low water absorption capacity, it performs better with a low water-cement ratio.

   *Comparison***:** While this dissertation emphasizes the water-cement ratio and the inclusion of copper slag, it underscores the importance of water quality in the mix. Our findings bring attention to the effects of pH and TDS on concrete strength, providing a more in-depth look into the water quality aspect.

5. **Fresh and hardened properties of five non-potable water mixtures and cured concrete** (Gokulanathan et al, 2021)

Key Finding: Higher TDS in water reduces the performance of fresh concrete. Seawater increased early-age compressive strength.

Comparison: Gokulanathan et al. emphasized the importance of TDS on concrete performance, particularly with seawater. While your dissertation observed a less influence of TDS, both studies align on the pivotal role of water quality in determining concrete's strength properties.

This dissertation adds depth to the existing knowledge of water quality effects on concrete strength. While earlier studies explored various water sources and additives, this research narrows the focus on pH and TDS levels. The consistent theme across all studies, including this one, can have an influence of water quality as it pertains to concrete strength. The pH level of water proved to have a more crucial role than TDS in determining concrete strength.

5.2. The Value of Concrete Mix Designs S1 and S2

The findings from this dissertation provide insights into the relationship between pH levels and the compressive strength of concrete. The compressive strength tests conducted on different concrete mix designs (S1 and S2) clearly demonstrate the influence of pH on the strength properties of the concrete.

Higher pH levels (pH 8) consistently led to higher compressive strengths compared to lower pH levels (pH 6) for both concrete mix designs. For instance, in mix design S1, concrete samples with pH 8 exhibited an average compressive strength of 253.3 Kg/cm^2, while samples with pH 6 showed a slightly lower than average compressive strength (i.e., 252.9 Kg/cm^2).

Similarly, in mix design S2, the average compressive strength for pH 8 was 257.8 Kg/cm^2, whereas for pH 6, it was 246.7 Kg/cm^2.

Moreover, the increase in total dissolved solid (TDS) levels (ranging from 1,000 to 4,000) had a relatively small impact on concrete strength. While higher TDS levels were generally associated with slightly lower compressive strengths, the effects of TDS on concrete performance was less compared to pH.

The control samples, with a pH of 7.74 and a TDS of 183 consistently exhibited compressive strength values across all ages (3, 7, and 28 days). These consistent results validate the accuracy and precision of the testing procedures employed in this dissertation, ensuring the reliability of the obtained data.

This dissertation highlights the critical importance of carefully selecting and controlling water quality and mix design parameters to achieve the desired strength and performance of concrete. Engineers and construction professionals can utilize the practical insights gained from this dissertation to concrete mix designs for specific construction projects, ensuring the desired strength and durability of concrete.

5.3 Future Research

This dissertation also emphasizes the need for further research into the long-term durability and structural integrity of concrete under varying pH and TDS conditions. Understanding the behavior of concrete in different environmental conditions can help engineers assess the long-term performance and sustainability of concrete structures.

The knowledge obtained from this dissertation serves as a resource for the development of comprehensive guidelines and standards for concrete mix design. By considering the effects of pH and TDS on the compressive strength of concrete, these guidelines can assist practitioners in selecting appropriate mix designs for various applications, ultimately promoting the adoption of sustainable and resilient concrete construction practices in the industry.

Recommendations for future research encompass various aspects related to build upon the existing knowledge and addressing the gaps identified in this dissertation, the following recommendations are proposed for future research. These recommendations encompass investigations that consider different pH and TDS levels, aiming to optimize concrete mix designs and enhance the performance of concrete structures in brackish water environments:

1. Comprehensive dissertation on Optimal Mix Design: Conduct a comprehensive dissertation to identify the best concrete mix design that considers different pH levels (6 and 8) and TDS levels (1,000, 2,000, 3,000, 4,000) of brackish water. Further research should focus on optimizing the proportions of cement, aggregates, water, and additives like fly ash and micro silica to achieve the highest compressive strength and overall durability.
2. Durability Performance under Realistic Conditions: Evaluate the long-term durability performance of concrete structures in real-world brackish water environments. This research should include monitoring the corrosion resistance and carbonation effects of concrete specimens exposed to varying pH and TDS levels over extended periods to simulate real-world conditions accurately.
3. Sustainable Concrete Mix Designs: Investigate the potential for developing sustainable concrete mix designs that utilize brackish water (pH 6 and 8, TDS 1,000, 2,000, 3,000, 4,000) while minimizing the environmental impact. This research should explore

alternative cementitious materials and their compatibility with brackish water to achieve eco-friendly and resource-efficient concrete production.

4. Impact of Brackish Water on Fresh Properties: Examine the influence of brackish water with different pH and TDS levels on the fresh properties of concrete, such as setting time, workability, and air content. Understanding how these properties are affected will aid in designing appropriate construction processes and ensuring high-quality concrete placement.
5. Performance of Brackish Water Concrete in Aggressive Environments: Evaluate the behavior of concrete produced with brackish water (pH 6 and 8, TDS 1,000, 2,000, 3,000, 4,000) in aggressive chemical environments, such as coastal areas with high chloride content. This research will provide insights into the concrete's resistance to chemical attacks and will guide material selection for specific applications.
6. Rheological Properties of Self-Consolidating Concrete: Further investigate the rheological properties of self-consolidating concrete with brackish water, considering different pH levels (6 and 8) and TDS levels (1,000, 2,000, 3,000, 4,000). Seek to gain and share a better understanding of the flow characteristics and stability of self-consolidating concrete. Seek ways to enhance its application in various construction scenarios.
7. Life Cycle Assessment: Conduct a comprehensive life cycle assessment (LCA) to evaluate the environmental impacts of using brackish water in concrete production (pH 6 and 8, TDS 1,000, 2,000, 3,000, 4,000) compared to traditional freshwater sources. This LCA should consider factors such as water usage, energy consumption, and waste generation to support sustainable decision-making.

8. Performance of Precast Concrete with Brackish Water: Investigate the use of brackish water (pH 6 and 8, TDS 1,000, 2,000, 3,000, 4,000) in precast concrete production and its impact on the curing process and overall product quality. This research will provide valuable insights into the feasibility of incorporating brackish water in precast concrete manufacturing.
9. Effects of Temperature Variations: Examine the effects of temperature variations on the mechanical properties of concrete produced with brackish water (pH 6 and 8, TDS 1,000, 2,000, 3,000, 4,000). This research should consider different climatic conditions and their impact on concrete performance over time.
10. Brackish Water Concrete for Offshore and Marine Structures: Assess the potential of using brackish water concrete (pH 6 and 8, TDS 1,000, 2,000, 3,000, 4,000) for offshore platforms, marine structures, and coastal infrastructure. Specific mix designs can be developed to ensure optimal performance and longevity in these challenging environments.

By conducting research in these specific directions and considering different pH and TDS levels, the construction industry can advance its understanding of the utilization of brackish water in concrete production. These recommendations will contribute to the development of sustainable practices, ensure the durability and efficiency of concrete structures, and support the implementation of brackish water in various construction applications.

5.4 Significance of Research

The significance of this research extends beyond the laboratory, offering valuable insights and contributions to several key areas:

5.4.1 Environmental Sustainability:

- In a world facing freshwater scarcity, this dissertation 's investigation into using brackish water in concrete addresses critical environmental concerns. By conserving freshwater resources, this research offers a sustainable solution that aligns with global efforts to mitigate water depletion.
- Resource Efficiency: This research provided a background on the optimization of concrete mix designs by incorporating brackish water and supplementary materials such as fly ash and micro silica. These efforts promote resource-efficient practices by reducing the consumption of raw materials and energy in concrete production.
- Advancements in Concrete Technology: Through a nuanced understanding of how pH and total dissolved solids impact concrete properties, this research drives advancements in concrete technology. These insights pave the way for innovation, leading to improved concrete mix designs and enhanced performance.
- Practical Implementation: The findings from this research provide practical knowledge for engineers and construction professionals. They can adopt brackish water and optimized mix designs to create structures with enhanced strength and durability, contributing to the longevity of infrastructure.

- Economic Viability: The utilization of brackish water and optimized concrete mix designs could have economic benefits by potentially reducing the costs associated with freshwater procurement. This research opens avenues for cost-effective construction practices.
- Reduced Carbon Footprint: By minimizing the need for freshwater and incorporating supplementary materials, this research contributes to lowering the carbon footprint of concrete production. This aligns with global efforts to combat climate change.
- Transdisciplinary Collaboration: This research bridges the gap between engineering, environmental science, and sustainability. This interdisciplinary approach fosters collaboration and holistic solutions for complex challenges.

In summary, this research holds promise for addressing environmental, economic, and technological challenges in the field of construction. By exploring the use of brackish water in concrete mix designs, this dissertation offers practical solutions for a more sustainable and resilient future.

5.5 This Dissertation Limitations

This dissertation has contributed insights to the field of concrete research, it is essential to recognize certain limitations inherent in this dissertation. These limitations include:

- Limited Applicability of Water to pH 6 and 8 and TDS (1,000 to 4,000) ppm: This dissertation focused solely on the effects of water with controlled pH levels (6 and 8) and varying total dissolved solids (TDS) levels of 1,000, 2,000, 3,000, and 4,000 ppm on the compressive strength of concrete. The findings may not directly apply to other types of water sources with different pH and TDS ranges, such as brackish water or seawater.

- Concrete Mix Design Variability: This dissertation utilized a specific concrete mix design with fixed proportions, including the water-to-cement ratio. Different mix designs and varying water-cement ratios could yield different outcomes when exposed to the same water quality. Therefore, this dissertation 's findings are specific to the selected mix design and may not be entirely representative of all possible concrete compositions.
- Limited Environmental Exposure: This dissertation primarily evaluated the compressive strength of concrete specimens at different curing periods, up to 28 days. However, concrete's long-term performance and durability in actual environmental conditions are affected by factors beyond compressive strength, such as shrinkage, creep, and resistance to aggressive elements. This research did not extensively address these aspects, requiring further investigations for a more comprehensive understanding of concrete behavior in real-world scenarios.
- Representativeness of Water Parameters: The water used in the study, while controlled for pH and TDS levels of 6 and 8 as well as 1,000, 2,000, 3,000, and 4,000 ppm, may not precisely represent the water quality in practical construction scenarios. The presence of additional impurities and varying mineral content in real-world water sources could yield different outcomes on concrete performance.

- Sample Size and Duration: This research was conducted within a defined time frame, which may have limited the sample size and duration of testing. A larger sample size and extended testing period could strengthen the statistical significance of the findings.
- Extrapolation to Field Conditions: While this study provides valuable insights into the effects of water quality with pH 6 and 8 and TDS 1,000, 2,000, 3,000, 4,000 ppm on compressive strength, caution should be exercised when extrapolating the results directly to field conditions. Real-world applications involve a multitude of variables and environmental factors that may interact differently with concrete compared to controlled laboratory settings.

Acknowledging and addressing these limitations will enhance the reliability and practical applicability of this dissertation's findings. Further research with a broader scope and consideration of real-world conditions will contribute to a more comprehensive understanding of the impact of water quality on concrete performance, facilitating the development of more resilient and sustainable construction practices. Despite these limitations, this dissertation's research outcomes contribute knowledge to the field of concrete technology. Addressing the limitations mentioned here could lead to a broader and more in-depth understanding of how water quality affects on the compressive strength of concrete, ultimately guiding the development of concrete structures for various construction applications.

5.6 Contributions to the Body of Knowledge:

This research has provided valuable data and results that offer specific insights and implications in several areas:

The pH and TDS Effect on Compressive Strength: This research findings demonstrate that pH and TDS concentrations have a considerable influence on the compressive strength of concrete mix designs. At pH 8 and TDS 2,000, the concrete exhibited the highest compressive strength in both 7-day and 28-day samples. Similarly, at pH 6 and TDS 2,000, there was an increase in compressive strength compared to other TDS levels. This highlights the importance of pH levels and their interaction with TDS in influencing concrete performance.

Optimal Conditions for Strength Enhancement: This research identifies the specific combinations of pH and TDS concentrations that lead to the highest compressive strengths. For instance, at pH 8, the optimal TDS concentration for enhanced compressive strength is 2,000 ppm, while at pH 6, TDS 2,000 also leads to the highest strength. This insight is crucial for concrete mix designers to achieve superior strength characteristics in their projects.

Water-to-Cement Ratio Importance: The study analyzes concrete mix designs with different water-to-cement ratios (0.4 and 0.6) and observes that TDS 2,000 consistently leads to an increase in compressive strength at both pH levels for all curing ages (7-day, 3-day, and 28-day).

Water Quality Management Importance: The findings underscore the significance of water quality management in concrete production. Poor-quality water with unfavorable pH and TDS levels can negatively impact the setting time, strength development, and overall performance of concrete. This research emphasizes the need to carefully select water sources and optimize water quality for concrete production.

Practical Guidance for Concrete Production: This research outcomes offer practical applications in the design and production of concrete with desired strength characteristics. Engineers can utilize the results to customize concrete mix designs based on the specific pH and TDS levels, thereby achieving the required compressive strength while minimizing water consumption and optimizing resources.

Enhancing Quality Control and Assurance: The compressive strength data obtained from this research can serve as an essential supplement to quality control measures for concrete production. Project managers and construction companies can use this data to closely monitor the strength characteristics of concrete samples at different curing durations, ensuring that the produced concrete meets the required performance standards.

Assessing Concrete Performance in Different Environments: This research enables the evaluation of concrete performance under varying environmental conditions. By analyzing the influence of pH and TDS levels on concrete strength in specific locations or exposure conditions, engineers can select appropriate mix designs tailored to environmental challenges, ensuring the durability and reliability of structures.

Promoting Sustainable Concrete Production: This research findings contribute to the development of sustainable concrete production practices. By optimizing mix designs based on water quality parameters, concrete producers can reduce waste, conserve natural resources, and promote environmentally friendly concrete production.

Guideline Development for Concrete Mix Design: The results obtained from this research provide a foundation for developing guidelines and standards for concrete mix design. These guidelines can aid engineers and practitioners in designing concrete mixes for specific applications, considering the effect of pH and TDS on compressive strength.

In conclusion, this research presents novel findings and insights, offering practical implications for concrete production, construction practices, and sustainable engineering. These contributions provided suggestions based on concrete engineering, enabling the development of more durable, efficient, and sustainable concrete structures in real-world applications.

5.7 List of Acronyms and Abbreviations

TDS - Total Dissolved Solids
cm - centimeter
kg - kilogram
m^3 - cubic meter
W/C - Water-to-Cement ratio
pH - potential of Hydrogen

5.8 Glossary of Terms

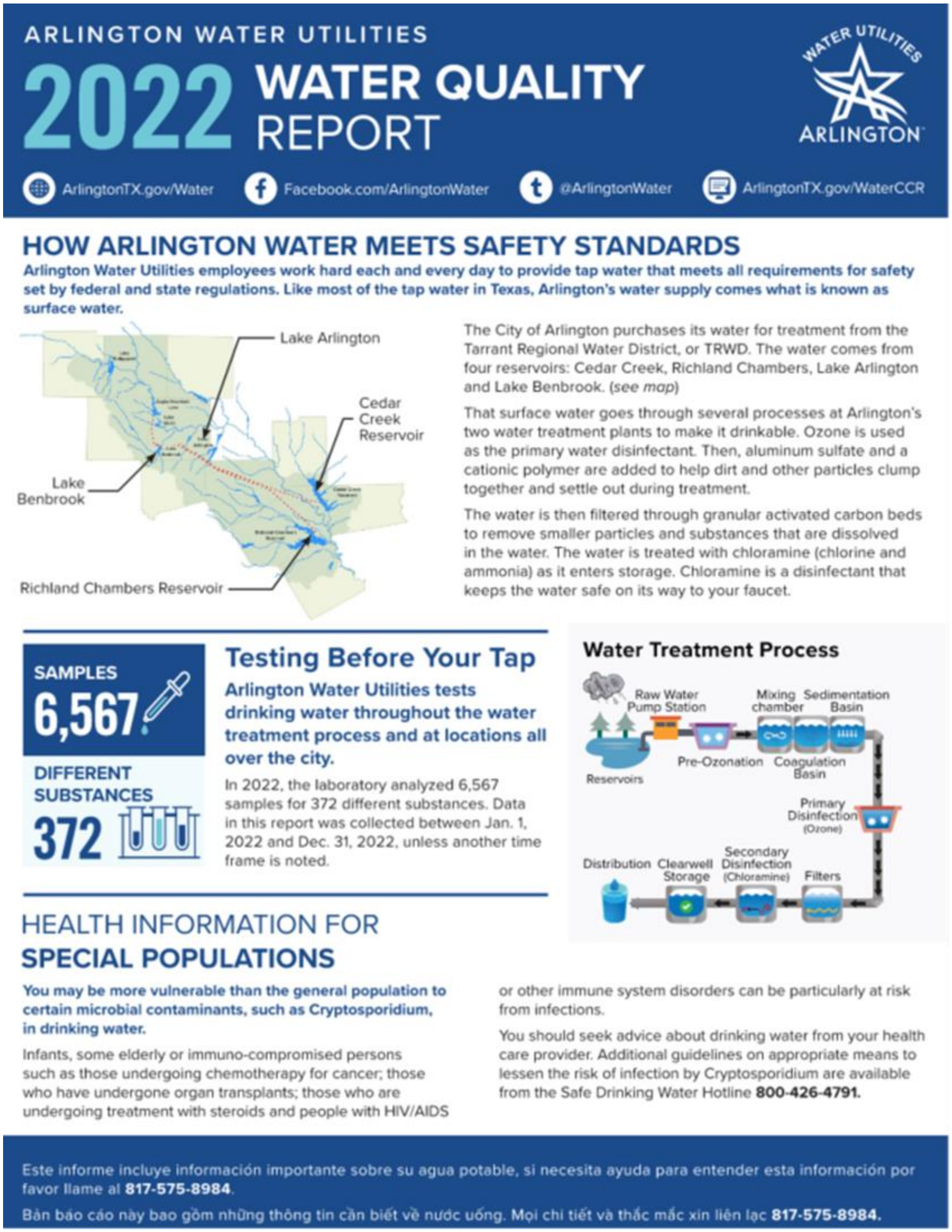
1. Compressive Strength: The maximum load a material can withstand before it fails in compression.
2. Workability: The ease with which a concrete mix can be mixed, placed, and finished.
3. Concrete Mix Design: The process of proportioning the ingredients of concrete to achieve the desired properties and performance.
4. Water-Cement Ratio: The ratio of the weight of water to the weight of cement in a concrete mix.
5. TDS (Total Dissolved Solids): The measure of the combined content of all inorganic and organic substances contained in water.
6. pH: A measure of the acidity or alkalinity of a solution, with values below 7 indicating acidity and values above 7 indicating alkalinity.
7. Cubic Centimeter (cm^3): A unit of volume equal to one milliliter.
8. Cubic Meter (m^3): A unit of volume equal to 1,000 liters.
9. Tesla: Unit of magnetic flux density
10. 1 N/mm^2 = 1 MPa = 1000000 pascals (Pa)
11. 1 kg/cm^2 = 98066.5 pascals (Pa)

APPENDIX A

A1. Arlington Water Utilities: Water Quality, Aggregates and Cement

Appendix A presents detailed information on the water quality, aggregates, and cement used by Arlington Water Utilities. This section is essential for understanding the foundational elements of concrete production and the quality of materials employed in various construction projects. This appendix provides a comprehensive overview of key factors affecting concrete's performance and durability in Arlington's infrastructure development.

A1.1 Arlington Water Utilities: 2022 Water Quality Report



ARLINGTON WATER UTILITIES

2022 WATER QUALITY REPORT

ArlingtonTX.gov/Water Facebook.com/ArlingtonWater @ArlingtonWater ArlingtonTX.gov/WaterCCR

HOW ARLINGTON WATER MEETS SAFETY STANDARDS

Arlington Water Utilities employees work hard each and every day to provide tap water that meets all requirements for safety set by federal and state regulations. Like most of the tap water in Texas, Arlington's water supply comes what is known as surface water.

The City of Arlington purchases its water for treatment from the Tarrant Regional Water District, or TRWD. The water comes from four reservoirs: Cedar Creek, Richland Chambers, Lake Arlington and Lake Benbrook. (*see map*)

That surface water goes through several processes at Arlington's two water treatment plants to make it drinkable. Ozone is used as the primary water disinfectant. Then, aluminum sulfate and a cationic polymer are added to help dirt and other particles clump together and settle out during treatment.

The water is then filtered through granular activated carbon beds to remove smaller particles and substances that are dissolved in the water. The water is treated with chloramine (chlorine and ammonia) as it enters storage. Chloramine is a disinfectant that keeps the water safe on its way to your faucet.

SAMPLES

6,567

DIFFERENT SUBSTANCES

372

Testing Before Your Tap

Arlington Water Utilities tests drinking water throughout the water treatment process and at locations all over the city.

In 2022, the laboratory analyzed 6,567 samples for 372 different substances. Data in this report was collected between Jan. 1, 2022 and Dec. 31, 2022, unless another time frame is noted.

Water Treatment Process

HEALTH INFORMATION FOR SPECIAL POPULATIONS

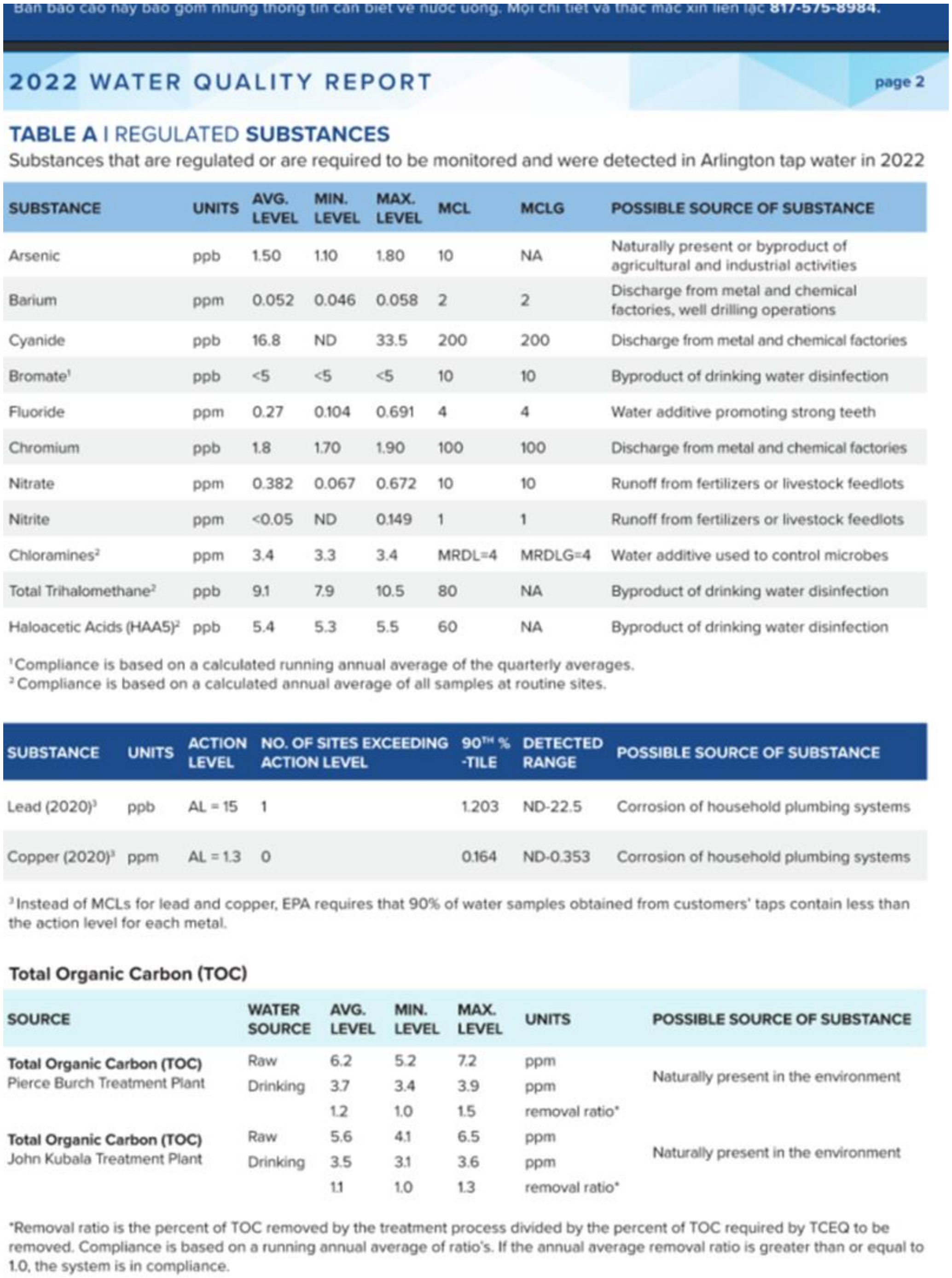
You may be more vulnerable than the general population to certain microbial contaminants, such as Cryptosporidium, in drinking water.

Infants, some elderly or immuno-compromised persons such as those undergoing chemotherapy for cancer; those who have undergone organ transplants; those who are undergoing treatment with steroids and people with HIV/AIDS or other immune system disorders can be particularly at risk from infections.

You should seek advice about drinking water from your health care provider. Additional guidelines on appropriate means to lessen the risk of infection by Cryptosporidium are available from the Safe Drinking Water Hotline **800-426-4791.**

Este informe incluye información importante sobre su agua potable, si necesita ayuda para entender esta información por favor llame al **817-575-8984**.

Bản báo cáo này bao gồm những thông tin cần biết về nước uống. Mọi chi tiết và thắc mắc xin liên lạc **817-575-8984.**



Ban bao cao nay bao gom nhung thong tin can biet ve nuoc uong. Mọi chi tiet va thac mac xin lien lạc **817-575-8984.**

2022 WATER QUALITY REPORT

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TABLE A I REGULATED SUBSTANCES

Substances that are regulated or are required to be monitored and were detected in Arlington tap water in 2022

SUBSTANCE	UNITS	AVG. LEVEL	MIN. LEVEL	MAX. LEVEL	MCL	MCLG	POSSIBLE SOURCE OF SUBSTANCE
Arsenic	ppb	1.50	1.10	1.80	10	NA	Naturally present or byproduct of agricultural and industrial activities
Barium	ppm	0.052	0.046	0.058	2	2	Discharge from metal and chemical factories, well drilling operations
Cyanide	ppb	16.8	ND	33.5	200	200	Discharge from metal and chemical factories
Bromate[1]	ppb	<5	<5	<5	10	10	Byproduct of drinking water disinfection
Fluoride	ppm	0.27	0.104	0.691	4	4	Water additive promoting strong teeth
Chromium	ppb	1.8	1.70	1.90	100	100	Discharge from metal and chemical factories
Nitrate	ppm	0.382	0.067	0.672	10	10	Runoff from fertilizers or livestock feedlots
Nitrite	ppm	<0.05	ND	0.149	1	1	Runoff from fertilizers or livestock feedlots
Chloramines[2]	ppm	3.4	3.3	3.4	MRDL=4	MRDLG=4	Water additive used to control microbes
Total Trihalomethane[2]	ppb	9.1	7.9	10.5	80	NA	Byproduct of drinking water disinfection
Haloacetic Acids (HAA5)[2]	ppb	5.4	5.3	5.5	60	NA	Byproduct of drinking water disinfection

[1] Compliance is based on a calculated running annual average of the quarterly averages.

[2] Compliance is based on a calculated annual average of all samples at routine sites.

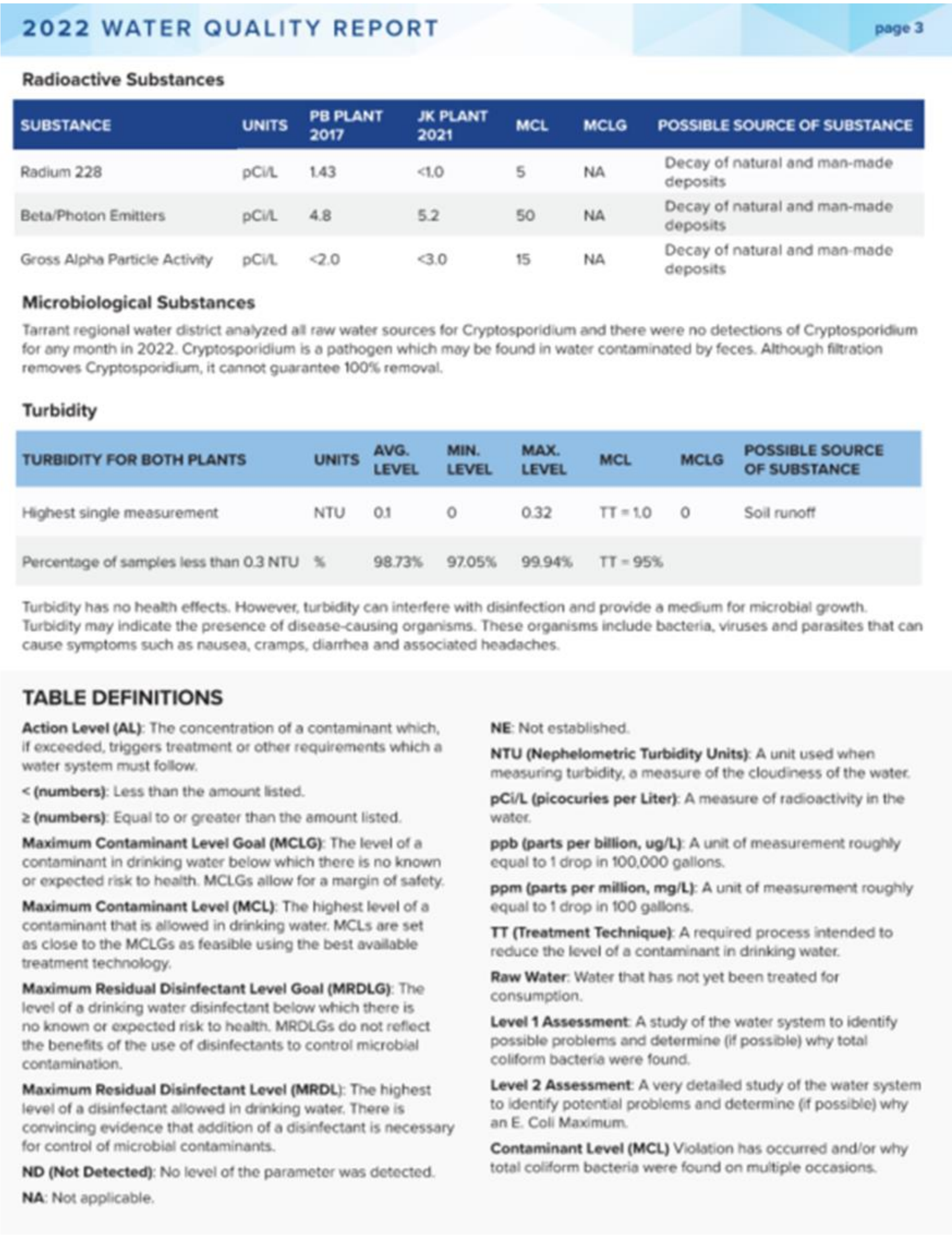
SUBSTANCE	UNITS	ACTION LEVEL	NO. OF SITES EXCEEDING ACTION LEVEL	90TH % -TILE	DETECTED RANGE	POSSIBLE SOURCE OF SUBSTANCE
Lead (2020)[3]	ppb	AL = 15	1	1.203	ND-22.5	Corrosion of household plumbing systems
Copper (2020)[3]	ppm	AL = 1.3	0	0.164	ND-0.353	Corrosion of household plumbing systems

[3] Instead of MCLs for lead and copper, EPA requires that 90% of water samples obtained from customers' taps contain less than the action level for each metal.

Total Organic Carbon (TOC)

SOURCE	WATER SOURCE	AVG. LEVEL	MIN. LEVEL	MAX. LEVEL	UNITS	POSSIBLE SOURCE OF SUBSTANCE
Total Organic Carbon (TOC) Pierce Burch Treatment Plant	Raw	6.2	5.2	7.2	ppm	Naturally present in the environment
	Drinking	3.7	3.4	3.9	ppm	
		1.2	1.0	1.5	removal ratio*	
Total Organic Carbon (TOC) John Kubala Treatment Plant	Raw	5.6	4.1	6.5	ppm	Naturally present in the environment
	Drinking	3.5	3.1	3.6	ppm	
		1.1	1.0	1.3	removal ratio*	

*Removal ratio is the percent of TOC removed by the treatment process divided by the percent of TOC required by TCEQ to be removed. Compliance is based on a running annual average of ratio's. If the annual average removal ratio is greater than or equal to 1.0, the system is in compliance.



2022 WATER QUALITY REPORT

Radioactive Substances

SUBSTANCE	UNITS	PB PLANT 2017	JK PLANT 2021	MCL	MCLG	POSSIBLE SOURCE OF SUBSTANCE
Radium 228	pCi/L	1.43	<1.0	5	NA	Decay of natural and man-made deposits
Beta/Photon Emitters	pCi/L	4.8	5.2	50	NA	Decay of natural and man-made deposits
Gross Alpha Particle Activity	pCi/L	<2.0	<3.0	15	NA	Decay of natural and man-made deposits

Microbiological Substances

Tarrant regional water district analyzed all raw water sources for Cryptosporidium and there were no detections of Cryptosporidium for any month in 2022. Cryptosporidium is a pathogen which may be found in water contaminated by feces. Although filtration removes Cryptosporidium, it cannot guarantee 100% removal.

Turbidity

TURBIDITY FOR BOTH PLANTS	UNITS	AVG. LEVEL	MIN. LEVEL	MAX. LEVEL	MCL	MCLG	POSSIBLE SOURCE OF SUBSTANCE
Highest single measurement	NTU	0.1	0	0.32	TT = 1.0	0	Soil runoff
Percentage of samples less than 0.3 NTU	%	98.73%	97.05%	99.94%	TT = 95%		

Turbidity has no health effects. However, turbidity can interfere with disinfection and provide a medium for microbial growth. Turbidity may indicate the presence of disease-causing organisms. These organisms include bacteria, viruses and parasites that can cause symptoms such as nausea, cramps, diarrhea and associated headaches.

TABLE DEFINITIONS

Action Level (AL): The concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow.

< (numbers): Less than the amount listed.

≥ (numbers): Equal to or greater than the amount listed.

Maximum Contaminant Level Goal (MCLG): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

Maximum Contaminant Level (MCL): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

Maximum Residual Disinfectant Level Goal (MRDLG): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contamination.

Maximum Residual Disinfectant Level (MRDL): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

ND (Not Detected): No level of the parameter was detected.

NA: Not applicable.

NE: Not established.

NTU (Nephelometric Turbidity Units): A unit used when measuring turbidity, a measure of the cloudiness of the water.

pCi/L (picocuries per Liter): A measure of radioactivity in the water.

ppb (parts per billion, ug/L): A unit of measurement roughly equal to 1 drop in 100,000 gallons.

ppm (parts per million, mg/L): A unit of measurement roughly equal to 1 drop in 100 gallons.

TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

Raw Water: Water that has not yet been treated for consumption.

Level 1 Assessment: A study of the water system to identify possible problems and determine (if possible) why total coliform bacteria were found.

Level 2 Assessment: A very detailed study of the water system to identify potential problems and determine (if possible) why an E. Coli Maximum.

Contaminant Level (MCL) Violation has occurred and/or why total coliform bacteria were found on multiple occasions.

$12.3 MILLION PROJECT

IS SET TO BE COMPLETED IN EARLY 2024

Construction started in 2022 on a new laboratory/ maintenance facility at the **John F. Kubala Water Treatment Plant** and the remodeling of a mini-laboratory used during the treatment process.

Photos courtesy Freese & Nichols

TABLE B I UNREGULATED CONTAMINANTS

These substances are not currently regulated by EPA. The purpose of unregulated contaminant monitoring is to assist EPA in determining the occurrence of unregulated contaminants in drinking water and whether future regulation is warranted.

SUBSTANCE	ANNUAL RUNNING AVERAGE OF ALL SAMPLES						POSSIBLE SOURCE OF SUBSTANCE
	UNITS	AVG. LEVEL	MIN. LEVEL	MAX. LEVEL	MCL	MCLG	
Chloroform	ppb	2.10	1.50	2.40	NE	NE	Byproduct of drinking water disinfection; not regulated individually; included in total Trihalomethanes
Bromodichloromethane	ppb	2.80	2.30	3.20	NE	NE	
Chlorodibromomethane	ppb	3.10	2.70	3.60	NE	60	
Bromoform	ppb	1.10	0.60	1.40	NE	NE	
Dichloroacetic Acid	ppb	3.62	3.44	3.86	NE	NE	Byproduct of drinking water disinfection; not regulated individually; included in Haloacetic Acids.
Bromoacetic Acid	ppb	2.31	2.24	2.39	NE	NE	
Dibromoacetic Acid	ppb	1.47	1.46	1.51	NE	NE	
Chloroacetic Acid	ppb	0.25	0.16	0.44	NE	NE	
Trichloroacetic Acid	ppb	0.03	ND	0.07	NE	300	

OTHER SUBSTANCES OF INTEREST

SUBSTANCE	UNITS	AVERAGE LEVEL	MINIMUM LEVEL	MAXIMUM LEVEL
Calcium	ppm	27.0	25.0	29.0
Chloride	ppm	21.0	18.0	24.0
Magnesium	ppm	3.99	3.67	4.3
pH	pH units	8.06	7.81	8.28
Potassium	ppm	4.93	4.86	4.99
Sodium	ppm	26.7	26.4	27
Sulfate	ppm	42.4	37.9	51.3
Alkalinity, Total	ppm	87.1	54.5	113
Total Dissolved Solids	ppm	194	160	235
Hardness, Total (as CaCO3)	ppm	95.1	77.4	130
	grains/gallon	5.6	4.5	7.6

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LEAD SERVICE LINE INVENTORIES
UNDERWAY NATIONWIDE

In late 2022, the U.S. Environmental Protection Agency updated guidelines for lead and copper monitoring by public drinking water providers throughout the country.

The new guidelines are known as the Lead and Copper Rule Revision (LCRR). Currently, Arlington Water Utilities records do not indicate any lead service lines in the portion of the water distribution system owned by the City. However, to achieve compliance with the LCRR, Arlington Water Utilities must verify whether lead materials are in any city-owned water service lines and create an inventory of that information by October 2024. The City must also create a similar inventory of the privately-owned water service lines, or pipes, which run from the water meter to the entrance to the home or business.

To learn more about this process, visit the Arlington Water Utilities webpage at **ArlingtonTX.gov/Water** and click on the Drinking Water Quality Questions tab.

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. **Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. The City of Arlington Water Utilities is responsible for providing high quality drinking water, but cannot control the variety of materials used in plumbing components.** When your water has been sitting for several hours unused, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to two minutes before using water for drinking or cooking.

If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods and steps you can take to minimize exposure is available from the **Safe Drinking Water Hotline** or at **EPA.gov/Safewater/Lead**

SUBSTANCES EXPECTED **TO BE IN DRINKING WATER**

The City of Arlington and the State of Texas both analyze your drinking water. Any regulated substances that were detected during the last year are shown in Table A on page 2, and all are well below the established maximum contaminant levels. All water dissolves substances from the ground as it flows over and through it.

Substances that may be present in raw water include:

Microbes
such as viruses and bacteria that come from septic systems, agricultural livestock operations and wildlife.

Salts and metals
that can be naturally occurring or the result of urban storm water runoff, industrial or domestic wastewater discharges or farming.

Pesticides and herbicides
that may come from a variety of sources such as agriculture, urban storm water runoff or residential uses.

Radioactive substances
that are naturally occurring.

Organic chemical substances
including synthetic and volatile organic chemicals that are byproducts of industrial processes and can also come from gas stations and urban stormwater runoff.

Contaminants may be found in drinking water that could cause taste, color, or odor problems but are not necessarily causes for health concerns. For more information, please call Laboratory Services at **817-575-8984**.

DO YOU HAVE PFAS QUESTIONS?

The U.S. EPA released a proposal on March 14, 2023 for the first National Primary Drinking Water standards for six per- and polyfluoroalkyl substances, also known as PFAS. PFAS substances have been used since the 1940s in industry and consumer products like nonstick cookware and fire fighting foam, according to the EPA. Because these substances break down slowly and can build up in the environment over time, they have gained the nickname "forever chemicals." PFAS compounds have been found in water, air, and soil.

Humans can ingest PFAS through a variety of foods, drinking water, or even through inhaling contaminated dust particles. Exposure to PFAS substances has been shown to have harmful effects on humans, especially when exposure is over long periods of time or during pregnancy or breast feeding.

Some of the health effects linked to these compounds by the EPA include cancers, heart attacks, strokes, and developmental (birth weight) problems.

The EPA has not had regulations in the past for the six PFAS chemicals in the March 14 announcement. However, some PFAS substances were included in a previous round of testing conducted and reported under the EPA's Unregulated Contaminants Monitoring Rule.

That rule, which is referred to as the UCMR, requires public water systems around the country to periodically test for unregulated compounds and report any occurrences. Each round of nationwide UCMR testing is referred to by a number, such as UCMR1, UCMR2, etc. Arlington Water Utilities tested for six PFAS substances in 2014 that were part of the UCMR3 round of testing. No detections of the PFAS chemicals were made in Arlington. The analytical methods used at the time would have reflected as little as 50 parts per trillion of the substances in Arlington's tap water. (One part per trillion is about a drop of water in 20 Olympic-sized pools.)

Though the new rules proposed in March 2023 won't take effect until later this year, Arlington Water Utilities and other utilities throughout Texas are already making plans to test for PFAS compounds as part of a fresh round of Unregulated Contaminants Monitoring Rule, called UCMR5. Arlington will begin UCMR5 testing of PFAS compounds in June 2023. Results from the first round of UCMR testing will be reported to the EPA a few months later. In this round of testing, the detection levels possible with newer analytical methods used will be much lower – at 4 ppt for most PFAS on the list.

To learn more about this process, visit the Arlington Water Utilities web page at **ArlingtonTX.gov/Water** and click on the Drinking Water Quality Questions tab.

WINNERS OF THE VALUE OF WATER MINI-POSTER CONTEST 2022

PREK

Ruby | Pope Elementary

KINDERGARTEN

Daniella | Goodman Elementary

FIRST GRADE

Kayra | Viridian Elementary

SECOND GRADE

Smitika | Swift Elementary

THIRD GRADE

Audrey | Starrett Elementary

FOURTH GRADE

Nancy | Ditto Elementary

ARLINGTON WATER UTILITIES LAB STAFF SPOTLIGHT

14 FULL-TIME and PART-TIME STAFF

TCEQ LICENSES:
2A, 3B, 2C, 2D

171 YEARS OF LABORATORY EXPERIENCE

3 MASTERS
9 BACHELORS

FOR MORE INFORMATION

Water Quality: 817-575-8984
Laboratory services, water quality questions or water quality problems. For questions about this brochure, ask for the laboratory.

Customer Care: 817-275-5931
Open new or transfer account, billing inquiries, water conservation, water and sewer rates.

Emergency Water and Sewer Services (24 hours):
817-459-5900
Service interruptions, water leaks, sewer problems.

Texas Commission on Environmental Quality (TCEQ):
512-239-1000

In accordance with Section 13.045 of the Texas Water Code, the City hereby provides notice that customer revenue derived from the sale of water to wholesale customers for resale was expended for various economic development and Capital Budget projects.

The Arlington Water Utilities Laboratory is accredited by the State of Texas, Texas Commission on Environmental Quality, under the National Environmental Laboratory Accreditation Program (NELAP). NELAP accreditation standards represent the best professional practices in the laboratory industry.

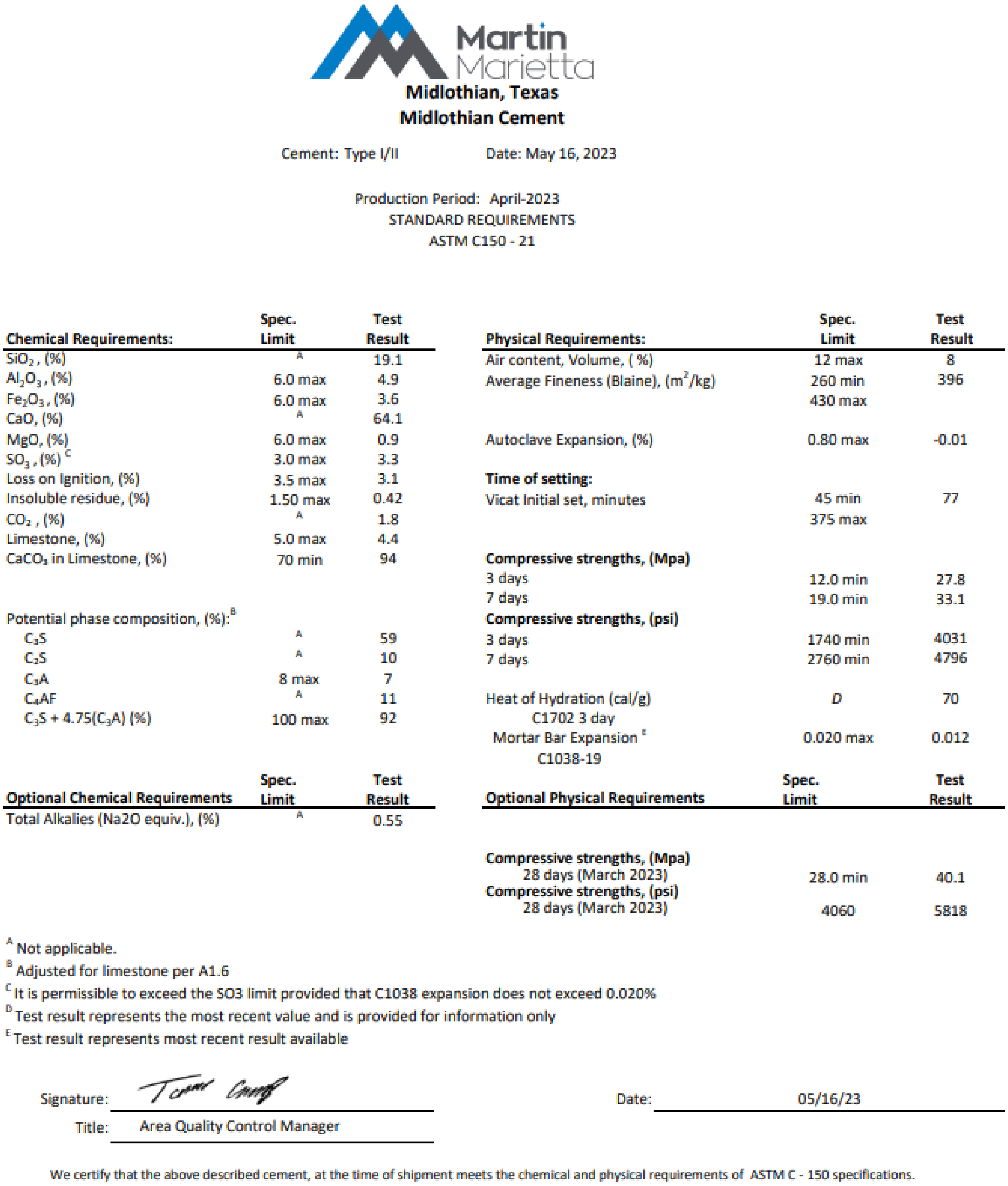
THE ENVIRONMENTAL PROTECTION AGENCY (EPA) SAFE DRINKING WATER HOTLINE

Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that water poses a health risk.

In order to ensure that tap water is safe to drink, the EPA prescribes regulations that limit the amount of certain substances in water provided by public water systems.

More information about contaminants and potential health effects can be obtained by calling the Environmental Protection Agency's (EPA) Safe Drinking Water hotline at **800-426-4791** or visiting the website at **EPA.gov/SafeWater.**

A1.2. Standard Cement Requirements Met by Martin Marietta for Cement Production Reported May 16, 2023



Martin Marietta

Midlothian, Texas
Midlothian Cement

Cement: Type I/II — Date: May 16, 2023

Production Period: April-2023
STANDARD REQUIREMENTS
ASTM C150 - 21

Chemical Requirements:	**Spec. Limit**	**Test Result**
SiO_2, (%)	[A]	19.1
Al_2O_3, (%)	6.0 max	4.9
Fe_2O_3, (%)	6.0 max	3.6
CaO, (%)	[A]	64.1
MgO, (%)	6.0 max	0.9
SO_3, (%) [C]	3.0 max	3.3
Loss on Ignition, (%)	3.5 max	3.1
Insoluble residue, (%)	1.50 max	0.42
CO_2, (%)	[A]	1.8
Limestone, (%)	5.0 max	4.4
$CaCO_3$ in Limestone, (%)	70 min	94
Potential phase composition, (%):[B]		
C_3S	[A]	59
C_2S	[A]	10
C_3A	8 max	7
C_4AF	[A]	11
$C_3S + 4.75(C_3A)$ (%)	100 max	92

Optional Chemical Requirements	**Spec. Limit**	**Test Result**
Total Alkalies (Na2O equiv.), (%)	[A]	0.55

Physical Requirements:	**Spec. Limit**	**Test Result**
Air content, Volume, (%)	12 max	8
Average Fineness (Blaine), (m^2/kg)	260 min 430 max	396
Autoclave Expansion, (%)	0.80 max	-0.01
Time of setting:		
Vicat Initial set, minutes	45 min 375 max	77
Compressive strengths, (Mpa)		
3 days	12.0 min	27.8
7 days	19.0 min	33.1
Compressive strengths, (psi)		
3 days	1740 min	4031
7 days	2760 min	4796
Heat of Hydration (cal/g) C1702 3 day	*D*	70
Mortar Bar Expansion [E] C1038-19	0.020 max	0.012

Optional Physical Requirements	**Spec. Limit**	**Test Result**
Compressive strengths, (Mpa) 28 days (March 2023)	28.0 min	40.1
Compressive strengths, (psi) 28 days (March 2023)	4060	5818

[A] Not applicable.
[B] Adjusted for limestone per A1.6
[C] It is permissible to exceed the SO3 limit provided that C1038 expansion does not exceed 0.020%
[D] Test result represents the most recent value and is provided for information only
[E] Test result represents most recent result available

Signature:
Title: Area Quality Control Manager
Date: 05/16/23

We certify that the above described cement, at the time of shipment meets the chemical and physical requirements of ASTM C - 150 specifications.

A1.3 Multi-Purpose Sand Specifications

https://www.sakrete.com/content/uploads/2021/07/Multi-Purpose Sand.pdf

MULTI-PURPOSE SAND

The Pro's Choice Since 1936

Sakrete® Multi-Purpose Sand is a graded and washed sand.

Use For:

- Custom concrete mixes
- Landscaping
- Pet areas
- Traction in winter
- Base or between patio pavers and bricks

SAKRETE MULTI–PURPOSE SAND IS NOT TO BE USED AS A BLASTING SAND

Yield/Water/Coverage:

Bag Size	Coverage	Yield
60 lb (27.7 kg)	Bag yields approximately .6 ft³ (0.02 m³)	Will fill an area approximately 7 ft² (.65m²) x 1" (25 mm) deep

NOTE: The yield is approximate and does not allow for waste and spillage. Length x width x depth (all in feet) will give the cubic volume. Divide the cubic volume of the area to be filled by 0.6 ft³. This will give the number of bags needed eg. 4 ft long x 3 ft wide x 4" (.33 ft.) deep = 4 ft³ divided by 0.6 ft³ gives the number of bags needed (7) in this example.

NOTE: Proper application and installation of all Sakrete products are the responsibility of the end user.

Safety:

READ and UNDERSTAND the Safety Data Sheet (SDS) before using this product. WARNING: Wear protective clothing and equipment. For emergency information, call CHEMTREC at 800-424-9300 or 703-527-3887 (outside USA).
KEEP OUT OF REACH OF CHILDREN.

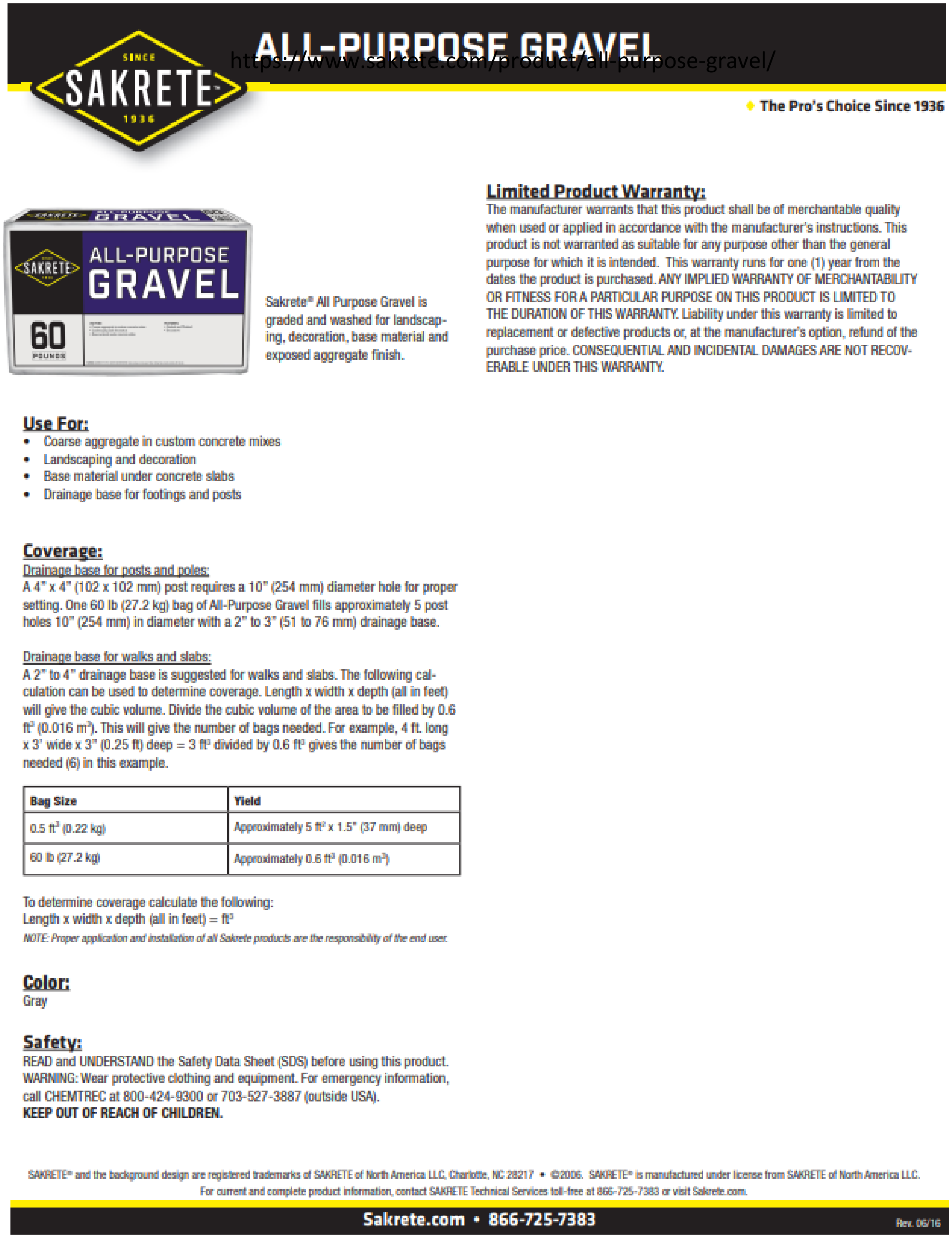
WARNING!
AVOID BREATHING DUST. CONTAINS CRYSTALLINE SILICA.
Prolonged exposure to crystalline silica is known to cause lung cancer or delayed lung injury, including silicosis. Take measures to eliminate or control dust. For prolonged exposure to dust, wear a respirator approved for protection against crystalline dust.

California Proposition 65 – This product contains Crystalline Silica, Quartz a chemical known to the state of California to cause cancer birth defects or other reproductive harm.

Limited Product Warranty:

The manufacturer warrants that this product is free from defects in material and workmanship and will perform per the manufacturer product literature in effect at the time of purchase. This warranty is for one (1) year from the date of purchase. Any implied warranty of merchantability or fitness for a particular purpose is limited to the duration of this express warranty. This warranty applied only if the product is used, in strict accord with manufacturer published instructions. The sole and exclusive remedy under this warranty is replacement of the defective product or refund of the purchase price, at manufacturer's option. CONSEQUENTIAL, SPECIAL, AND INCIDENTAL DAMAGES ARE NOT RECOVERABLE UNDER THIS WARRANTY. All claims under this warranty must be submitted to manufacturer by calling 866-725-7383. This warranty gives you specific legal rights, and you may also have other rights which vary from state to state.

A1.4 All-Purpose Gravel Specifications



ALL-PURPOSE GRAVEL

https://www.sakrete.com/product/all-purpose-gravel/

The Pro's Choice Since 1936

Sakrete® All Purpose Gravel is graded and washed for landscaping, decoration, base material and exposed aggregate finish.

Use For:

- Coarse aggregate in custom concrete mixes
- Landscaping and decoration
- Base material under concrete slabs
- Drainage base for footings and posts

Coverage:

Drainage base for posts and poles:
A 4" x 4" (102 x 102 mm) post requires a 10" (254 mm) diameter hole for proper setting. One 60 lb (27.2 kg) bag of All-Purpose Gravel fills approximately 5 post holes 10" (254 mm) in diameter with a 2" to 3" (51 to 76 mm) drainage base.

Drainage base for walks and slabs:
A 2" to 4" drainage base is suggested for walks and slabs. The following calculation can be used to determine coverage. Length x width x depth (all in feet) will give the cubic volume. Divide the cubic volume of the area to be filled by 0.6 ft^3 (0.016 m^3). This will give the number of bags needed. For example, 4 ft. long x 3' wide x 3" (0.25 ft) deep = 3 ft^3 divided by 0.6 ft^3 gives the number of bags needed (6) in this example.

Bag Size	Yield
0.5 ft^3 (0.22 kg)	Approximately 5 ft^2 x 1.5" (37 mm) deep
60 lb (27.2 kg)	Approximately 0.6 ft^3 (0.016 m^3)

To determine coverage calculate the following:
Length x width x depth (all in feet) = ft^3

NOTE: Proper application and installation of all Sakrete products are the responsibility of the end user.

Color:

Gray

Safety:

READ and UNDERSTAND the Safety Data Sheet (SDS) before using this product. WARNING: Wear protective clothing and equipment. For emergency information, call CHEMTREC at 800-424-9300 or 703-527-3887 (outside USA).
KEEP OUT OF REACH OF CHILDREN.

Limited Product Warranty:

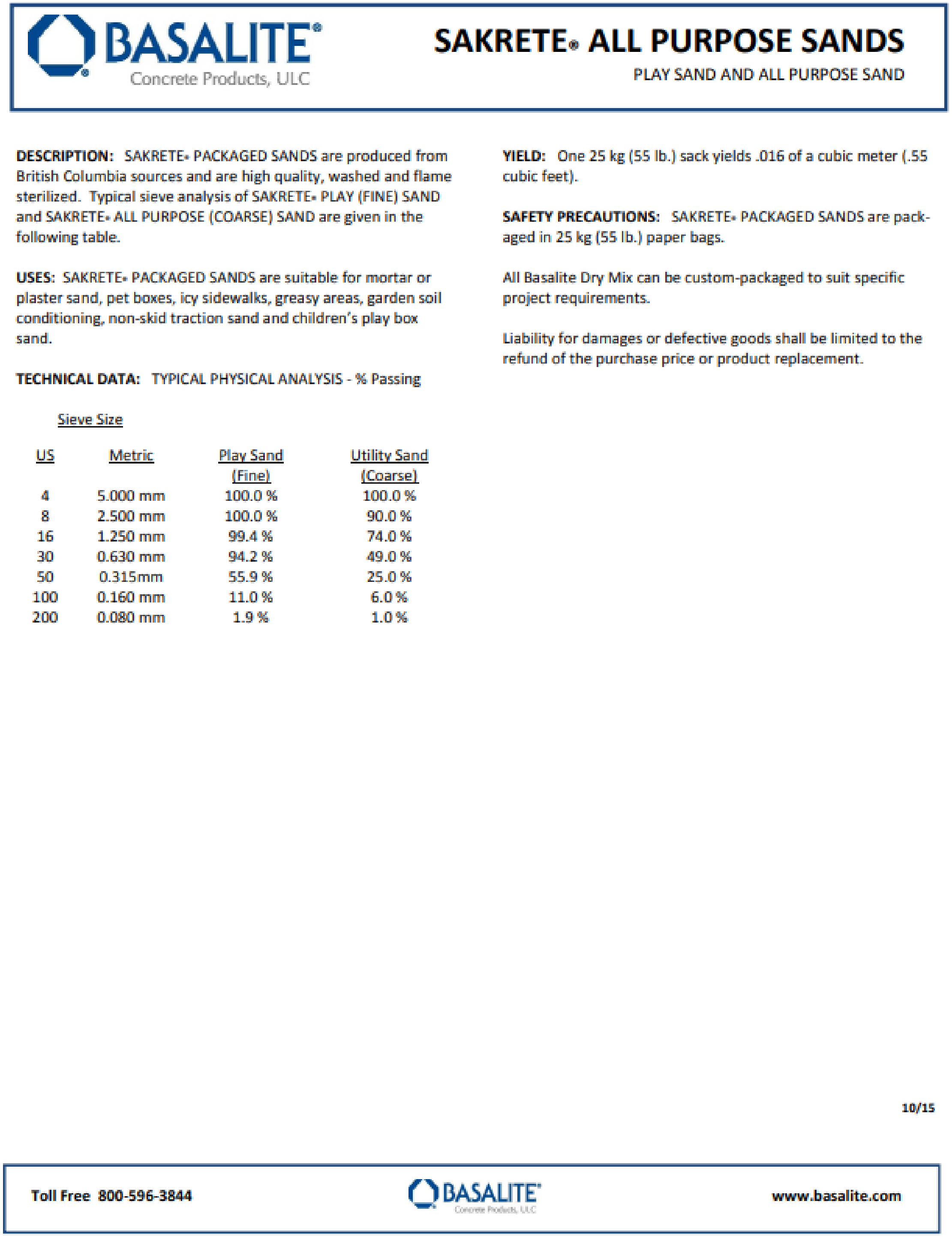
The manufacturer warrants that this product shall be of merchantable quality when used or applied in accordance with the manufacturer's instructions. This product is not warranted as suitable for any purpose other than the general purpose for which it is intended. This warranty runs for one (1) year from the dates the product is purchased. ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE ON THIS PRODUCT IS LIMITED TO THE DURATION OF THIS WARRANTY. Liability under this warranty is limited to replacement or defective products or, at the manufacturer's option, refund of the purchase price. CONSEQUENTIAL AND INCIDENTAL DAMAGES ARE NOT RECOVERABLE UNDER THIS WARRANTY.

For current and complete product information, contact SAKRETE Technical Services toll-free at 866-725-7383 or visit Sakrete.com.

Sakrete.com • 866-725-7383

Rev. 06/16

A1.5. All Purpose Sand Specifications



BASALITE®
Concrete Products, ULC

SAKRETE® ALL PURPOSE SANDS

PLAY SAND AND ALL PURPOSE SAND

DESCRIPTION: SAKRETE® PACKAGED SANDS are produced from British Columbia sources and are high quality, washed and flame sterilized. Typical sieve analysis of SAKRETE® PLAY (FINE) SAND and SAKRETE® ALL PURPOSE (COARSE) SAND are given in the following table.

USES: SAKRETE® PACKAGED SANDS are suitable for mortar or plaster sand, pet boxes, icy sidewalks, greasy areas, garden soil conditioning, non-skid traction sand and children's play box sand.

TECHNICAL DATA: TYPICAL PHYSICAL ANALYSIS - % Passing

Sieve Size

US	Metric	Play Sand (Fine)	Utility Sand (Coarse)
4	5.000 mm	100.0 %	100.0 %
8	2.500 mm	100.0 %	90.0 %
16	1.250 mm	99.4 %	74.0 %
30	0.630 mm	94.2 %	49.0 %
50	0.315mm	55.9 %	25.0 %
100	0.160 mm	11.0 %	6.0 %
200	0.080 mm	1.9 %	1.0 %

YIELD: One 25 kg (55 lb.) sack yields .016 of a cubic meter (.55 cubic feet).

SAFETY PRECAUTIONS: SAKRETE® PACKAGED SANDS are packaged in 25 kg (55 lb.) paper bags.

All Basalite Dry Mix can be custom-packaged to suit specific project requirements.

Liability for damages or defective goods shall be limited to the refund of the purchase price or product replacement.

10/15

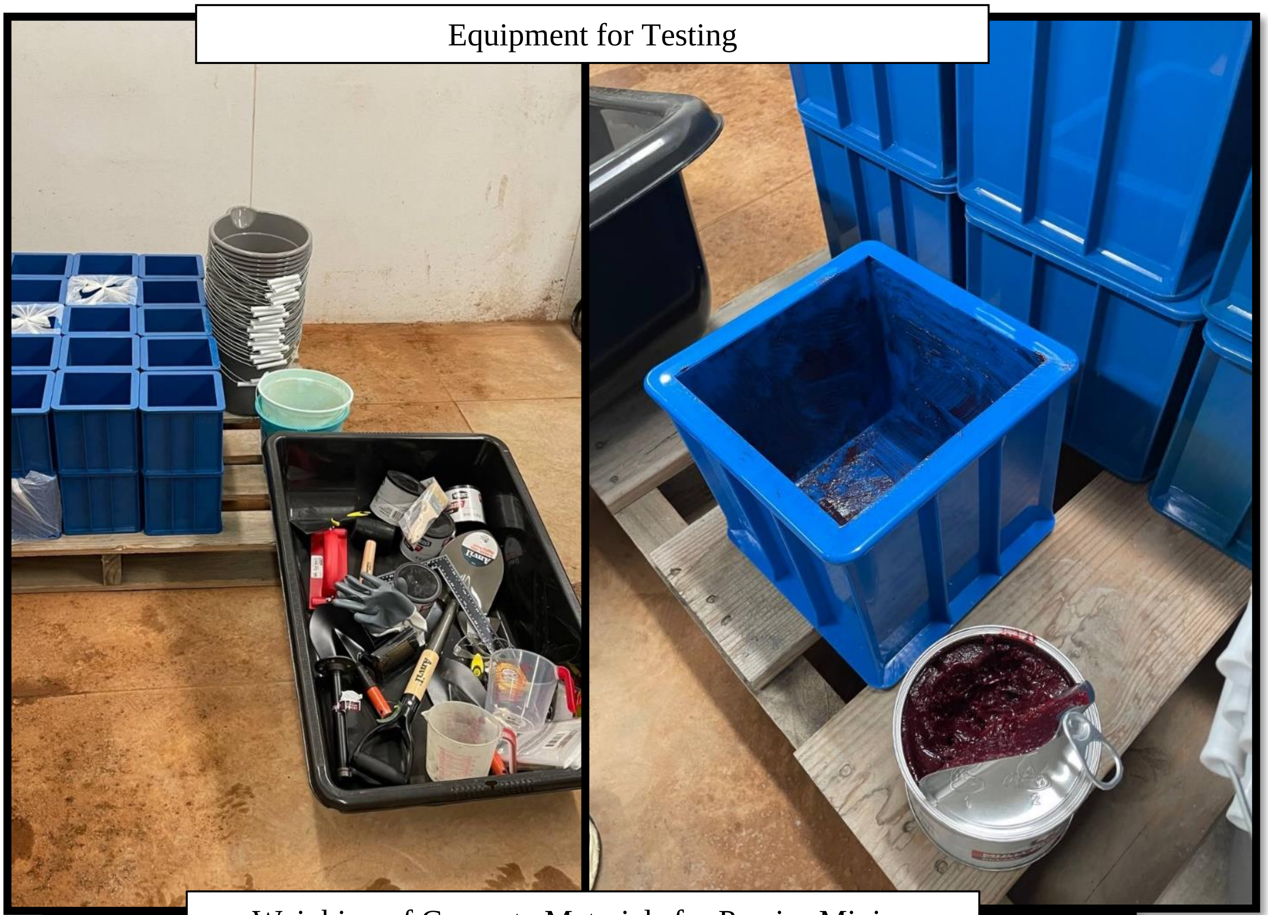
Toll Free 800-596-3844 BASALITE® Concrete Products, ULC www.basalite.com

Appendix B

A Visual Representation of the Research Stages

Appendix B presents a visual representation of the various stages involved in the research conducted for this study. This visual aid complements the main dissertation and aims to provide a concise and easy-to-understand overview of the research process. It offers a graphical representation of the key steps taken to collect, analyze, and interpret the data, helping readers grasp the research methodology and progression.

Equipment for Testing



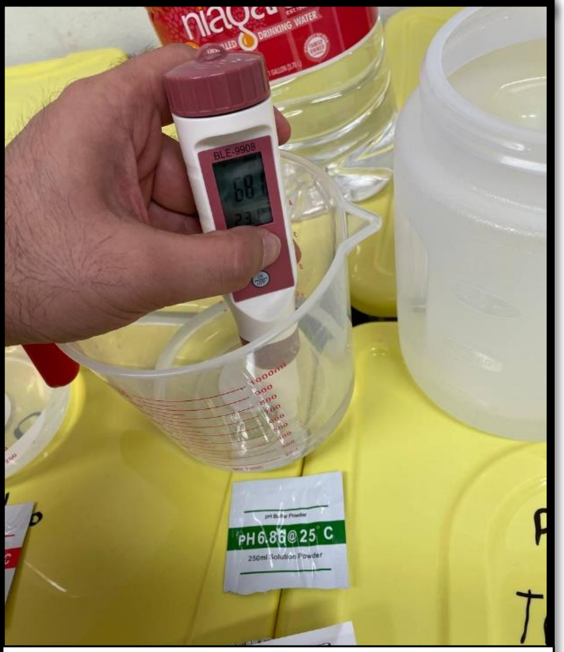
Weighing of Concrete Materials for Precise Mixing

Water Preparation for Concrete Mixing and Curing

Water Preparation for Concrete Mixing and Curing

Water Preparation for Concrete Mixing and Curing

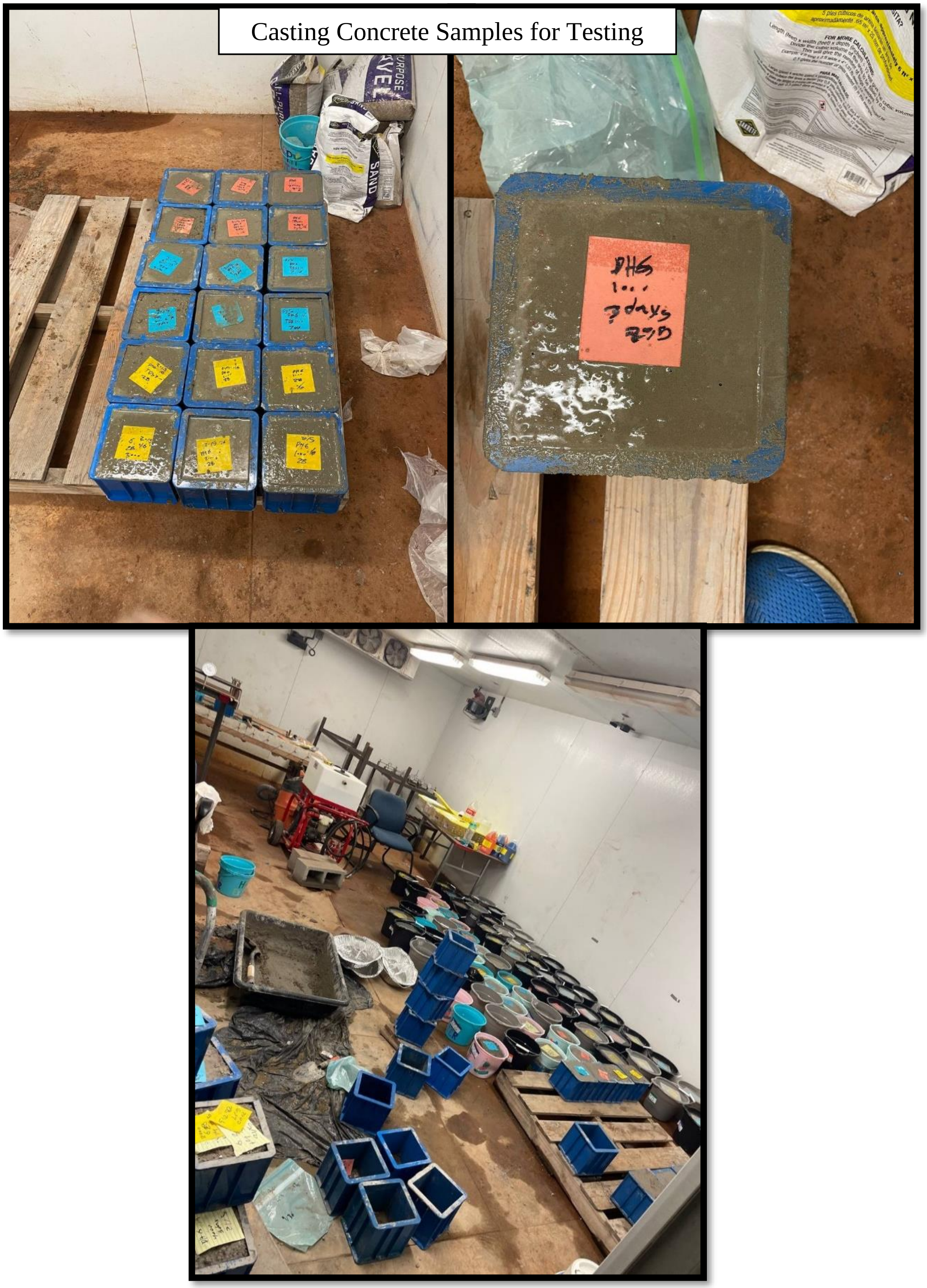
Concrete Mixing Process



Calibrating the pH and TDS Meters for Accurate Measurements

Concrete Mixing Process

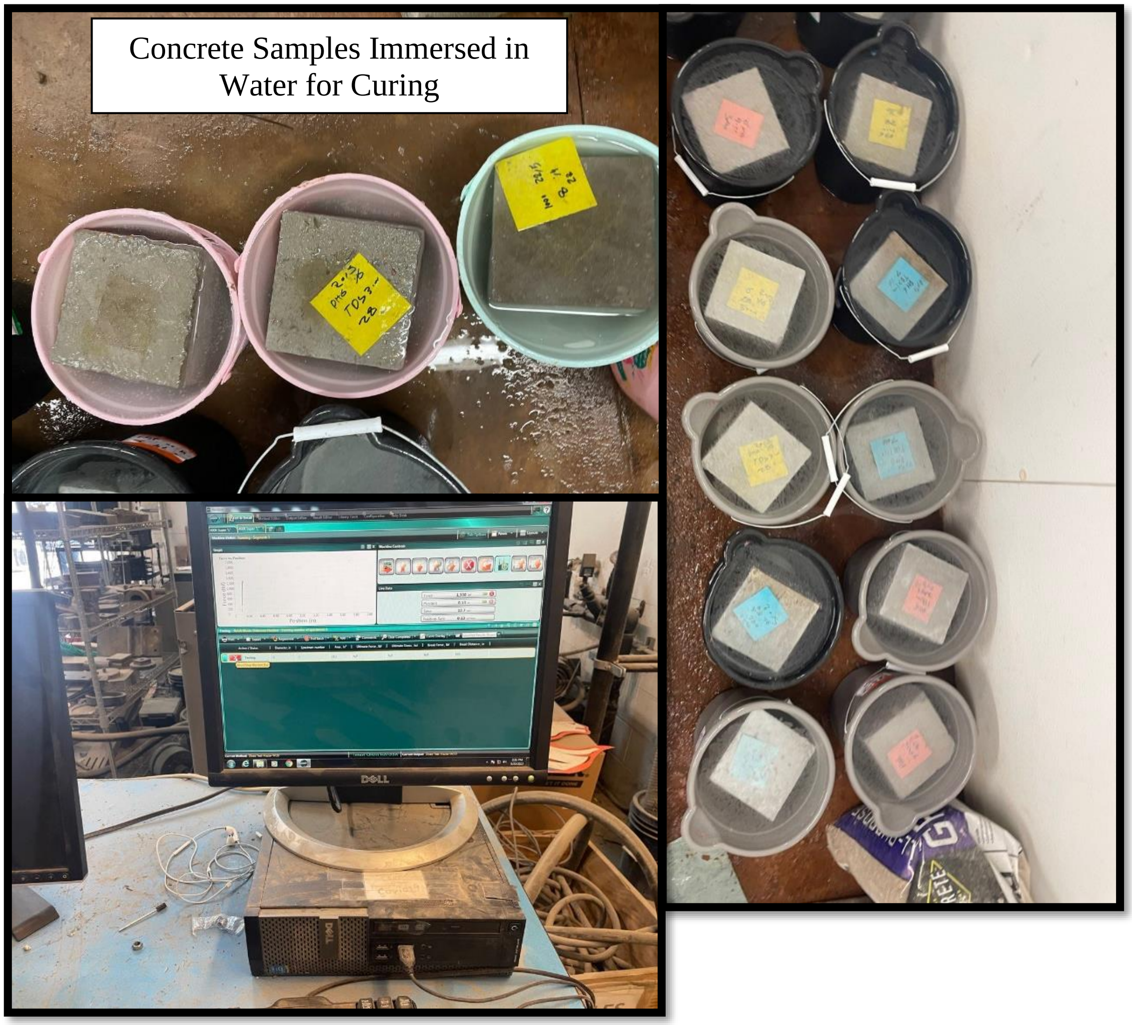
Casting Concrete Samples for Testing



Concrete Samples Immersed in Water for Curing

Leveling

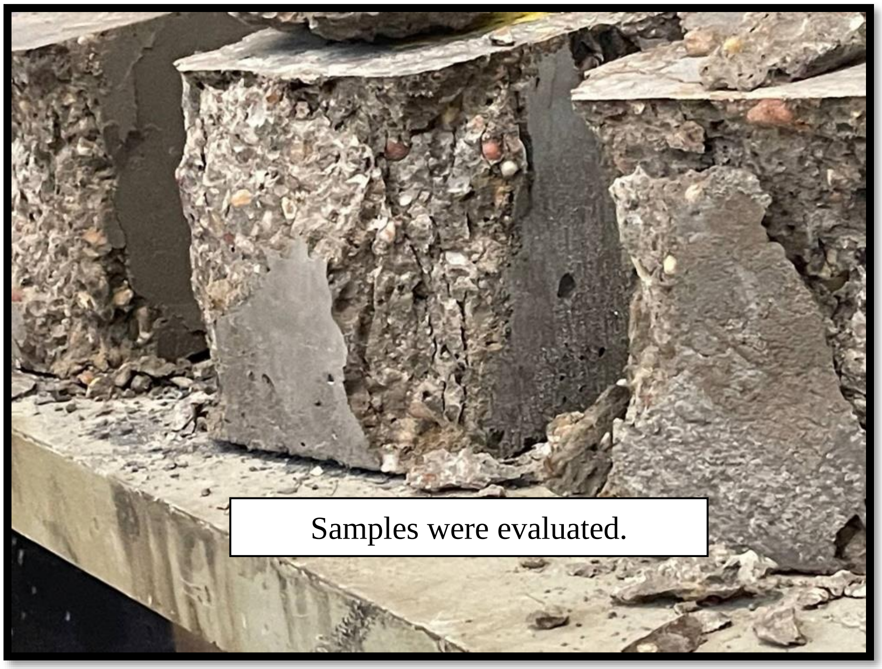
Concrete Samples Undergoing Compressive Strength Testing.



Concrete Samples Immersed in Water for Curing

Concrete Samples Undergoing Compressive Strength Testing.

Concrete Samples Undergoing Compressive Strength Testing.


Samples were evaluated.

Samples were evaluated.

Samples were evaluated.


Samples were evaluated.

Samples were evaluated.

Samples were evaluated.

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