# EVALUATION OF THE EFFECT OF UREA-SALT SOLUTION ON THE DURABILITY OF REINFORCED CONCRETE AND TENSILE STRENGTH OF STEEL REINFORCEMENT

BY

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# PLAGIARISM

This work **EVALUATION OF THE EFFECT OF UREA-SALT SOLUTION ON THE DURABILITY OF REINFORCED CONCRETE AND TENSILE STRENGTH OF STEEL REINFORCEMENT** by OMORUYI, Esogie Benedict with matric number ENG2002184 of the department of Civil Engineering, Faculty of Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

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# CERTIFICATION

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# DEDICATION

This work is dedicated to God Almighty. I thank Him for keeping me alive to see this day and giving me good health to keep going in life despite my shortcomings.

Secondly, it is dedicated to My Parents, Mr. And Mrs. Omoruyi, for always being there for me in any way possible, most especially in my academics and life coachings and for their unwavering support for me all through my life with them as their Son.

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# ABSTRACT

This study examines how curing reinforced concrete in a urea-salt solution, which simulates urine, affects its compressive strength and durability. This is compared to concrete cured in fresh water. The research addresses concerns about the decline of concrete structures in environments that are biologically or chemically harsh, such as areas often contaminated by urine. Understanding the impact of such exposure on concrete performance is important for improving the design and maintenance of durable structures under these conditions.

The experimental work involved casting twenty concrete cubes, each measuring 100 × 100 × 100 mm, using a mix ratio of 1:2:4 and a water-cement ratio of 0.5. Ten cubes were cured in fresh water, while the other ten were cured in a urea-salt solution made with 10 g of urea and 2 g of sodium chloride ($NaCl$) per liter of water. The cubes were tested for compressive strength after 14 and 28 days of curing using a compression testing machine. The data gathered were analyzed and compared to evaluate the impact of the urea-salt solution on concrete performance.

The average compressive strengths were 18.81 $N/mm^2$ and 23.17 $N/mm^2$ for the 14- and 28-day fresh-water samples, and 18.15 $N/mm^2$ and 17.81 $N/mm^2$ for the urea-salt-cured samples which indicates that concrete cured in fresh water showed normal strength growth with age. In contrast, the concrete cured in the urea-salt solution had a slight decrease in compressive strength over time. It was concluded that exposure to the urea-salt solution restricts full hydration and weakens concrete durability with extended contact. It is advised that structures in areas prone to urine contamination be shielded from direct exposure.

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# ACRONYMS

**OPC** – Ordinary Portland Cement

**ASTM** – American Society for Testing and Materials

**NIS** – Nigerian Industrial Standard

**UTS** – Ultimate Tensile Strength

**MIC -** Microbiologically influenced corrosion

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of the Study

Concrete is the most widely used construction material worldwide due to its versatility, strength, and affordability. It plays an important role in building infrastructure, including buildings, bridges, roads, and water-retaining structures (Neville, 2011). However, despite its high compressive strength, concrete is weak in tension and can degrade when exposed to harsh agents. One major concern for the durability of reinforced concrete is the corrosion of the embedded steel reinforcement, which can severely weaken the structure over time.

Corrosion of steel in concrete is a complex electrochemical process that speeds up when aggressive ions, like chlorides and sulfates, enter the material. Traditionally, the main causes of this deterioration have been marine environments and deicing salts. Recently, researchers have started focusing on less conventional but increasingly relevant exposure conditions, including contact with biologically contaminated fluids such as urine. In many urban and informal areas, reinforced concrete elements like bridge piers, roadside barriers, and utility poles often encounter urine from humans or animals. Still, the long-term effects of this exposure on concrete and steel are not well studied.

Urine contains compounds like urea, ammonia, chlorides, and other organic and inorganic materials that can affect the chemical environment within concrete. This reaction can gradually weaken the concrete's strength and durability (Akinsola et al., 2012). When these substances seep into the porous structure of concrete, they can lower its alkalinity and weaken the passive film that protects the steel reinforcement (Bertolini et al., 2013). While the effects of chlorides and sulfates are well documented, the impact of urine or urea-based solutions is less understood (Mehta and Monteiro, 2014). This research aims to fill this gap by examining the mechanical and durability properties of reinforced concrete cured in a urea-salt solution that mimics biological exposure.

This study will create a simulated urine-contaminated environment using a controlled urea-NaCl solution. This approach will allow for a systematic investigation of how such exposure affects concrete compressive strength and the tensile strength of the embedded steel reinforcement. By placing steel bars in concrete cubes and curing them in the simulated solution, the research hopes to replicate real-life conditions while maintaining control in the laboratory.

## 1.2 Statement of the Problem

Despite the common use of reinforced concrete in cities and rural areas, its long-term durability under unusual exposure conditions is not well understood. While researchers have extensively studied chloride-induced corrosion from seawater and deicing salts, they have paid little attention to biological exposures like urine. This is surprising because such exposure is common in real-world infrastructure, especially in places where public urination happens regularly (Neville, 2011; Goyal & Siddique, 2011).

The main issue is that engineers do not have reliable data on how biologically active fluids, particularly urea-based solutions, affect the concrete matrix and the embedded steel. Without this information, structures that face these conditions may break down too soon. This can create safety hazards, lead to higher maintenance costs, and shorten service life (Papadakis, 1999; Mehta & Monteiro, 2014). Additionally, the lack of standard testing methods for this type of exposure makes it hard for engineers to design or repair structures effectively (Adewuyi & Adegoke, 2008).

This study aims to address this knowledge gap by measuring the effect of a urea-salt solution on both the compressive strength of concrete and the tensile strength of embedded steel reinforcement. The results will offer valuable insights for civil engineers, infrastructure planners, and material scientists (Olonade & Oyelade, 2015).

## 1.3 Aim and Objectives

The aim of this study is to evaluate the effects of curing concrete in a urea–salt (simulated urine) solution on its durability and compressive strength.

To achieve this aim, the following objectives have been established:

a. To determine the compressive strength of concrete specimens cured in a urea–salt solution for 14 and 28 days.

b. To evaluate the corresponding compressive strength of specimens cured in fresh water under the same conditions.

c. Compare the performance of both curing media to establish the effect of urea–salt exposure on concrete strength development and durability.

## 1.4 Scope of the Study

This study evaluates concrete cubes under two curing conditions: fresh water and a urea-salt solution, which simulates urine. The urea-salt solution was made by dissolving 10 grams of urea and 2 grams of sodium chloride in one liter of water. We cast and tested twenty cubes for compressive strength after 14 and 28 days of curing. The analysis focuses on assessing compressive strength and visually observing surface deterioration. Although the study initially intended to assess both concrete and reinforcement performance, the experimental scope was limited to concrete compressive strength evaluation due to laboratory constraints. The experimental procedure follows relevant ASTM standards (ASTM C39, 2019).

## 1.5 Justification of the Study

There is a clear gap in current research on how durable reinforced concrete is when it comes into contact with biological contaminants. Seawater and other saline environments have been studied extensively, but the effects of urea and urine-based exposures have not been explored as much. Since these exposures often occur in real-life situations, especially in poorly regulated areas, this research is both important and needed.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

Reinforced concrete is essential to modern construction due to its strength, versatility, and cost-effectiveness. However, its durability faces challenges from environmental factors, especially in harsh conditions with chemical and biological agents. While much research has focused on common deterioration processes like chloride and sulfate attack, the effects of biologically active fluids, such as urine or urea-based solutions, have not been thoroughly studied. This chapter reviews the literature on reinforced concrete durability, the corrosion processes affecting steel reinforcement, and the specific consequences of urea-salt solutions. It brings together findings from past studies, highlights areas needing more research, and sets up a framework for assessing how a urea-NaCl solution impacts concrete compressive strength and steel tensile strength.

## 2.2 Overview of Concrete Durability

Concrete durability is its ability to endure environmental and mechanical stresses throughout its intended lifespan without a major loss of structural integrity or usability (Marcos-Meson et al., 2018). Reinforced concrete combines the compressive strength of concrete with the tensile strength of steel. This combination makes it popular for infrastructure like bridges, buildings, and marine structures. However, processes such as carbonation, chloride ingress, sulfate attack, and freeze-thaw cycles can harm its durability. These processes break down the concrete matrix and start steel corrosion (Liu et al., 2021). They also shorten the service life of structures, increase maintenance costs, and create safety risks.

The durability of concrete relies on its mix design, curing conditions, and environmental exposure. Factors like water-cement ratio, aggregate quality, and the use of supplementary cementitious materials (like fly ash or slag) affect its resistance to harmful agents (Provis, 2024). For example, a low water-cement ratio decreases porosity, which limits the entry of harmful substances. However, the behavior of concrete under unconventional conditions, such as contact with biological fluids, is not well understood. This gap calls for focused research.

### 2.2.1 Protective Mechanisms in Reinforced Concrete

The high alkalinity of concrete, with a pore solution pH of 12.5 to 13.5, creates a passive oxide layer on embedded steel which protects the steel from corrosion (Abdelrahman et al., 2016). Calcium hydroxide and other alkaline compounds in the cement matrix help maintain this passive state. However, aggressive agents can disturb this protective environment.

Carbonation occurs when atmospheric carbon dioxide reacts with calcium hydroxide, reducing the pH to below 9. This change makes the steel vulnerable to corrosion (Cao et al., 2019). Similarly, chloride ions can seep into the concrete cover. When they surpass a critical level of 0.4 to 1% by cement weight in Portland cement concrete, they start pitting corrosion, which is very localized and damaging (Cao et al., 2019).

The thickness of the concrete cover plays an important role in durability. A thicker cover slows down the entry of aggressive agents, while insufficient cover speeds up deterioration (Ghanbari et al., 2023). Furthermore, the bond between steel and concrete is vital for effective load transfer. However, corrosion-induced cracking weakens this bond, which affects structural performance. Understanding these mechanisms is key to assessing the impact of unconventional agents like urea.

### 2.2.2 Role of Mix Design in Durability

Concrete mix design plays a key role in durability. Using supplementary cementitious materials, such as fly ash or ground granulated blast-furnace slag, lowers permeability and improves resistance to chloride ingress and sulfate attack (Liu et al., 2021). For instance, adding 20% fly ash can cut chloride diffusion by 30 to 40% compared to ordinary Portland cement (Provis, 2024). Admixtures like superplasticizers make the mix easier to work with without adding more water, which further boosts durability (Jassam et al., 2020). However, these strategies' effectiveness in biologically aggressive environments, like those containing urea, has not been tested. This reveals a need for more research.

## 2.3 Concrete Permeability and Pore Structure

Concrete durability depends greatly on its ability to resist harmful agents like water, chlorides, sulfates, and other aggressive ions. These substances can enter concrete through three main ways: diffusion, absorption, and permeation (Neville, 2011). Diffusion happens when ions move from a*reas of h*igh concentration to low concentration within the concrete's pore water. Absorption refers to the capillary uptake o*f liquids* into the surface pores. Permeation involves flow through interconnected v*oids under* hydraulic pressure (Mindess et al., 2003).

The pore structure of the concrete, including its porosity, pore size distribution, and connectivity, plays a key role in how quickly and deeply these aggressive substances can penetrate (Mehta & Monteiro, 2014). A denser and less connected pore network slows down the rate of ingress and improves durability. However, when the pore network is highly interconnected or has microcracks, the concrete becomes more permeable, making it more vulnerable to chemical attack and degradation.

### 2.3.1 Factors Affecting Permeability

Several factors affect the permeability of concrete, such as the water-cement ratio, curing conditions, cement composition, and the use of supplementary cementitious materials (SCMs) like fly ash, silica fume, or slag (Thomas, 2013). Lower water-cement ratios typically create denser microstructures with less capillary porosity. This improves resistance to ion transport. On the other hand, higher water-cement ratios increase pore connectivity, which allows chlorides, urea, and other contaminants to enter.

In this research, a mix ratio of 1:2:4 and a water-cement ratio of 0.5 were used. This represents typical Grade 25 concrete. While this mix is suitable for general construction, it may be more prone to ionic ingress compared to higher strength, lower porosity mixes. Poor curing can further increase permeability. It can cause incomplete hydration, leading to unfilled pores and microvoids in the cement matrix (Neville, 2011).

### 2.3.2 Permeability in the Context of Urea–Salt Exposure

When concrete comes into contact with a urea-salt solution, both physical and chemical processes can change its pore structure. The dissolved urea can break down into ammonia and carbon dioxide. These byproducts may react with calcium hydroxide in the cement paste, leading to the creation of more voids or microcracks (Papadakis, 1999). At the same time, the salt (sodium chloride) can form crystals within the pores as the solution dries or evaporates. This generates internal pressure that expands and weakens the surrounding cement matrix (Pereira et al., 2018).

With prolonged exposure, these combined effects can make the concrete more porous. This allows even more harmful ions to penetrate and speed up deterioration. This ongoing cycle of chemical change and pore expansion explains why concrete cured or exposed to urea-salt environments may experience strength loss and surface damage over time when compared to specimens cured in fresh water.

## 2.4 Corrosion Mechanisms in Steel Reinforcement

Corrosion of steel reinforcement is an electrochemical process that involves anodic (oxidation) and cathodic (reduction) reactions. The steel serves as an anode, releasing electrons. Meanwhile, oxygen and water at the cathode help create hydroxide ions, resulting in rust formation (Cao et al., 2019). This process needs an electrolyte, such as pore water in concrete, and is sped up by aggressive ions like chlorides. Chloride-induced corrosion is especially harmful because it causes pitting, which decreases the steel's cross-sectional area and tensile strength (Akinsola et al., 2012).

### 2.4.1 Factors Influencing Corrosion

Several factors influence corrosion rates, including concrete quality, environmental exposure, and steel properties. High-quality concrete with low permeability slows down ion ingress, while cracked or porous concrete speeds it up (Marcos-Meson et al., 2018). Environmental factors like humidity, temperature, and the presence of chlorides or sulfates also play a significant role. For example, marine environments expose concrete to high chloride concentrations (3–5% NaCl), which greatly increases the risk of corrosion (Akinsola et al., 2012). The geometry of reinforcement bars, such as diameter and surface features, impacts corrosion susceptibility. Smaller-diameter bars show more relative cross-sectional loss (Ghanbari et al., 2023).

### 2.4.2 Impact on Structural Performance

Corrosion products, like iron oxides, take up 2 to 6 times more space than the original steel. This expansion creates internal stresses that lead to cracking and spalling of the concrete cover (Ghanbari et al., 2023). These cracks allow harmful agents to enter, resulting in a cycle of further damage. The reduction in the steel's cross-section lowers its tensile strength. At the same time, weakened bonding between the steel and concrete hinders load transfer, which can cause structural failure in serious cases (Cao et al., 2019). It's important to understand these processes to evaluate the effects of urea–NaCl solutions, as they may cause extra chemical interactions.

### 2.4.3 Corrosion Monitoring Techniques

Monitoring corrosion is essential for evaluating the durability of reinforced concrete. Techniques like half-cell potential measurement (ASTM C876) and linear polarization resistance give us information about corrosion activity and rates (Cao et al., 2019). Half-cell potential helps locate areas with active corrosion. Values below -350 mV suggest a high chance of corrosion. Linear polarization resistance measures the corrosion current, allowing us to estimate the loss of steel mass (Gürten et al., 1993). These methods will be useful for assessing steel corrosion in the urea-NaCl exposure experiments of this study.

## 2.5 Effect of Curing Media on Concrete Properties

Curing is one of the most important processes affecting the performance and durability of concrete. It keeps the cement hydrated, allowing the concrete to gain the required strength and structural integrity. The curing environment is crucial in determining the concrete's mechanical and durability properties. Traditionally, concrete is cured in clean water, which supplies the necessary moisture for hydration and helps create a dense, well-bonded structure. However, certain conditions—like coastal areas, industrial sites, and places with biological waste—may involve alternative or contaminated curing methods. These can significantly change the hydration process and long-term performance of the concrete (Neville, 2011).

The type of curing medium can either improve or damage concrete strength, depending on its chemical makeup. Fresh water provides an ideal environment for full hydration, leading to more calcium silicate hydrate (C-S-H) gels that enhance strength. On the other hand, curing in harsh media such as salty water, acidic solutions, or urea-based solutions can prevent proper hydration and cause calcium hydroxide ($Ca(OH)_2$) to leach from the cement matrix (Adewuyi & Adegoke, 2008). Salty water, for example, introduces chloride ions into the concrete pores. These can react with cement hydrates or build up in voids, resulting in expansive compounds and microcracking (Mehta & Monteiro, 2014).

Many studies have shown that concrete cured in salty conditions often has lower compressive strength compared to specimens cured in water. This happens because chloride and sulfate ions disrupt the hydration process and interfere with stable hydrate formation. Similarly, curing environments contaminated with urea or biological materials can change the pH and ionic makeup of the pore solution. The presence of urea and its breakdown products—like ammonia and carbon dioxide—can affect the pore structure and weaken the area between aggregates and cement paste (Goyal & Siddique, 2011; Papadakis, 1999). Over time, these chemical changes can increase porosity, decrease density, and lower compressive strength.

The duration of curing also interacts with the medium to affect final strength. For example, while concrete cured in water usually gains strength over time, concrete cured in harsh environments may stagnate or lose strength due to ongoing chemical attacks. This is consistent with the findings of Olonade and Oyelade (2015), who saw that concrete cured in seawater initially gained strength but later suffered microstructural damage after extended exposure. These findings support the idea that while alternative curing methods can mimic real environmental conditions, they often reduce the mechanical and durability properties of concrete compared to traditional curing in fresh water.

In this study, comparing concrete cured in fresh water with that cured in a urea-salt solution offers insights into how chemically harsh curing environments affect hydration, pore structure, and compressive strength development. Understanding these effects is crucial for evaluating the long-term durability of concrete structures exposed to environments with urea, salt, or similar contaminants.

### 2.6 Composition of Urea in Biological Fluids

Urea ($CO(NH_2)_2$) is an important part of urine, making up 2 to 3% of its makeup. It is found alongside chlorides (0.3 to 0.6%), ammonia, and various organic compounds (Gürten et al., 1993). In water, urea breaks down to produce ammonia ($NH_3$) and carbon dioxide ($CO_2$), which temporarily raises the pH of the solution. This process is sped up by enzymes like urease in biological settings and can change the chemical conditions within concrete (Akinsola et al., 2012). The chlorides present in urine make its interaction with reinforced concrete even more complicated because chlorides can cause corrosion.

#### 2.6.1 Interaction with Concrete and Steel

Urea breaks down to products that can seep into the porous structure of concrete. This may lower the alkalinity of the pore solution. Ammonia can raise the local pH temporarily, but long-term exposure might react with cement hydrates and change the microstructure (Gürten et al., 1993). Chlorides found in urine increase corrosion risks by disrupting the protective oxide layer on steel. Although urea is not very corrosive by itself, when mixed with chlorides and other salts in a simulated urine solution, it may have a compounding effect. This needs further testing.

### 2.6.2 Urea Hydrolysis and Environmental Impact

Urea hydrolysis is a process that takes time and depends on temperature, pH, and microbial activity. In biological environments, bacteria that produce urease speed up hydrolysis and quickly create ammonia (Provis, 2024). This can cause localized increases in pH, which might affect the stability of the cement matrix. In concrete, ammonia can react with calcium compounds, forming soluble salts that raise porosity over time. Although this study does not consider microbial effects, understanding how urea behaves chemically helps us interpret its effects on concrete and steel.

## 2.7 Effects of Urea on Concrete Durability

Research on urea's impact on concrete is limited but offers some insights. Gürten et al. (1993) studied urea as an alternative de-icer. They exposed concrete cubes to 5% and saturated urea solutions for 30 months. The study found no significant chemical damage to the concrete matrix without prior chloride exposure. However, physical deterioration, like surface scaling, occurred when urea crystallized on concrete surfaces that were not washed by rain. This suggests that urea's physical effects, such as crystallization pressure, may lead to surface damage under certain conditions (Gürten et al., 1993).

### 2.7.1 Microstructural Analysis

Microstructural analysis using mercury intrusion porosimetry showed no significant changes in the pore structure of concrete exposed to urea alone (Gürten et al., 1993). However, when concrete was treated with sodium chloride beforehand, exposure to urea did not reduce chloride-induced damage. This means that urea’s protective ability is limited in environments contaminated with chloride. The study also noted that urea’s hydrolysis products might interact with calcium hydroxide in concrete, possibly forming secondary compounds, although these reactions were not fully described (Gürten et al., 1993). These findings highlight the importance of studying urea together with chlorides, as suggested in this research.

### 2.7.2 Long-Term Exposure Considerations

Long-term exposure to urea may cause effects that short-term studies do not show. Repeated wetting and drying cycles, similar to real-world urine exposure, could worsen surface scaling and micro-cracking. This may increase permeability and allow chloride to enter (Provis, 2024). This study looks at 14 and 28 day curing periods to offer initial insights into these effects. There is potential for future research on longer exposure times.

## 2.8 Corrosion Behavior on Steel Reinforcement

The corrosion behavior of steel in concrete exposed to urea is less studied than that caused by chlorides. Gürten et al. (1993) observed corrosion potentials of steel electrodes in concrete slabs exposed to urea solutions. They found no significant corrosion initiation when there was no prior chloride contamination. However, in concrete contaminated with chlorides, urea neither reduced nor significantly increased corrosion rates. This suggests that urea plays a neutral role in situations where corrosion already exists (Gürten et al., 1993). This indicates that urea’s effect may depend on the presence of chlorides, but it could still contribute to damage when both are present.

### 2.8.1 Tensile Strength Considerations

Corrosion weakens the tensile strength of steel reinforcement by reducing its cross-sectional area and creating stress points at pitting locations (Cao et al., 2019). Although there are no direct studies on urea's impact on tensile strength, it could change the concrete's protective environment and indirectly affect steel properties. For example, urea hydrolysis might raise the local pH, but the chlorides involved could compromise the passive layer, resulting in pitting and a loss of tensile strength. This study will focus on tensile strength testing to offer new insights into these effects.

### 2.8.2 Interaction with Chloride Ions

The presence of chlorides in a urea-NaCl solution, as used in this study, is likely to dominate corrosion behavior. Chlorides cause pitting corrosion, which is worse than uniform corrosion because it is localized (Cao et al., 2019). In this case, urea may change the chemical environment. It could enhance the effects of chlorides by increasing ion mobility or changing pH dynamics. This interaction needs to be tested experimentally.

## 2.9 Effects of Salt Solutions on Concrete and Steel

Sodium chloride (NaCl) is a known cause of concrete deterioration. Chlorides seep into the concrete cover. They reach the steel and start pitting corrosion when the chloride level surpasses a certain limit (Cao et al., 2019). Jassam et al. (2020) examined concrete that was exposed to salty soils with NaCl concentrations between 10% and 25%. They found that compressive strength significantly decreased, especially in weaker mixes like 1:2:4. The study also noted that long-term exposure, beyond 28 days, worsened the loss of strength, showing that chloride damage depends on time.

### 2.9.1 Seawater Exposure

Seawater, which contains 3 to 5% NaCl and sulfates, is a common aggressive environment. Akinsola et al. (2012) found that curing with seawater improved early compressive strength by speeding up hydration. However, it also raised the risk of corrosion for embedded steel in structures exposed to air. The presence of sulfates causes chemical damage by forming expansive compounds like ettringite, which can lead to cracking (Sun et al., 2015). The simulated urea-NaCl solution used in this study resembles some features of seawater exposure. However, it also introduces unique chemical interactions because of urea, which requires careful investigation.

### 2.9.2 Combined Effects of Salts and Urea

The mix of urea and NaCl in the proposed simulated urine solution may create effects that aren't seen with chloride alone. The products from urea's breakdown could boost ion movement or change the pH of the concrete pore solution, possibly increasing corrosion caused by chloride (Gürten et al., 1993). This study's controlled experiments seek to measure these interactions and offer insights into their combined effects on concrete and steel.

## 2.10 Role of Fibers in Durability

Fiber-reinforced concrete (FRC) improves durability by increasing tensile strength and controlling crack growth. Adding steel fibers at a volume fraction of 1 to 2% boosts compressive and tensile strength by 50 to 70%. It also reduces crack widths, which limits the entry of harmful agents (Marcos-Meson et al., 2018). This ability to bridge cracks improves corrosion resistance by keeping the protective environment around the concrete intact (Liu et al., 2021). While FRC is not the main focus of this study, its principles are important for reducing the impacts of urea and NaCl exposure.

### 2.10.1 Practical Applications

FRC is more often used in tough settings, like marine and wastewater infrastructure, where long-lasting materials are essential. Marcos-Meson et al. (2018) found that steel fibers can delay the start of corrosion by up to 30% when compared to plain concrete. This offers a possible way to improve resistance to biological exposures. Future research could look into how FRC performs in environments contaminated with urea.

### 2.10.2 Limitations of FRC

Despite its benefits, FRC has limitations. These include higher costs and difficulties in achieving even fiber distribution. Overloading fibers, beyond a 2% volume fraction, can reduce workability and increase porosity. This negates the durability benefits (Liu et al., 2021). These factors must be considered when assessing FRC's potential for biologically aggressive environments.

## 2.11 Characteristics of UHPC

Ultra-high-performance concrete (UHPC) has compressive strengths over 150 MPa. It features low porosity, high density, and improved durability (Su et al., 2024). Its dense microstructure prevents aggressive agents from entering, which makes it suitable for tough environments. Research by Ganesh and Murthy (2019) showed that UHPC containing steel fibers has better resistance to chloride entry. This reduces corrosion rates by as much as 50% when compared to regular concrete.

### 2.11.1 Relevance to Biological Exposures

While UHPC's performance in chloride-rich environments is well-documented, its behavior in urea exposure remains untested. The high cement content and cost of UHPC limit its widespread use. However, its potential to resist biological deterioration makes it a candidate for future research in infrastructure exposed to urine (Su et al., 2024). This study's findings on conventional concrete could help in developing UHPC for these applications.

### 2.11.2 Sustainability Considerations

UHPC has a high cement content, which raises concerns about sustainability because of the carbon footprint created during cement production. Recent research has looked into replacing cement with supplementary materials, such as ground granulated blast-furnace slag. This change can reduce $CO_2$ emissions by 20 to 30% while keeping the material durable (Ganesh & Murthy, 2019). These improvements could make UHPC more suitable for biologically aggressive environments, but more research is needed.

### 2.12.1 Compressive Strength Testing

Compressive strength testing (ASTM C39) is a standard method for checking concrete durability. Cubes or cylinders undergo uniaxial compression, and reductions in strength show deterioration (Cao et al., 2019). This study will use this method to compare urea, NaCl-cured samples with control samples.

### 2.12.2 Tensile Strength Testing

Tensile strength testing of steel reinforcement (ASTM A370) requires extracting bars from concrete and applying tensile load. Corrosion-induced pitting reduces the effective cross-section and lowers tensile capacity (Cao et al., 2019). This study will use this method to measure the effects of urea and NaCl on steel.

### 2.12.3 Microstructural and Corrosion Analysis

Techniques such as mercury intrusion porosimetry and scanning electron microscopy evaluate microstructural changes. Half-cell potential and linear polarization resistance gauge corrosion activity (Gürten et al., 1993). These methods will assist in visual assessments of degradation in this study.

### 2.12.4 Non-Destructive Testing

Non-destructive testing methods, like ultrasonic pulse velocity and dynamic modulus of elasticity, assess internal damage and material integrity without harming the specimens (Provis, 2024). Ultrasonic pulse velocity can reveal micro-cracking; a 5-10% reduction in velocity points to significant deterioration (Gürten et al., 1993). These methods could support destructive tests in future studies of concrete exposed to urea.

## 2.13 Environmental and Biological Exposures

Biological exposures, like urine, create complex chemical interactions because of their components, which include urea, chlorides, ammonia, and organic compounds. Although microbiologically influenced corrosion poses a risk in wastewater infrastructure, its impact on concrete exposed to urine is not well researched (Provis, 2024). This study examines the chemical effects, using a synthetic urea, NaCl solution to mimic urine exposure.

### 2.13.1 Real-World Relevance

In cities and nearby areas, structures like bridge piers and utility poles often come into contact with urine, but typical design codes do not consider this exposure. The chemical makeup of urine, along with its commonness, highlights the need for specific research (Akinsola et al., 2012).

### 2.13.2 Microbial Interactions

Although this study leaves out microbial effects, the organic content in urine can encourage microbial growth. This may lead to microbiologically influenced corrosion (Provis, 2024). For instance, bacteria that produce urease speed up the breakdown of urea. This process increases ammonia production and changes pH levels. Future research could look into these interactions to better understand how urine affects concrete durability.

## 2.14 Previous Works Done

### 2.14.1 Studies on Urea Exposure

Gürten et al. (1993) conducted a key study on urea as a de-icer. They exposed concrete cubes and slabs to 5% and saturated urea solutions for 30 months. No significant chemical damage was noted in chloride-free concrete, but surface scaling happened due to urea crystallization. In chloride-contaminated concrete, urea did not reduce corrosion. This suggests that its protective role is limited (Gürten et al., 1993)

### 2.14.2 Chloride and Seawater Studies

Akinsola et al. (2012) studied the effects of seawater and found that it increased early compressive strength but also raised the risk of corrosion from chlorides. Jassam et al. (2020)

reported that NaCl concentrations of 10 to 25% in salty soils reduced compressive strength by 10 to 20%. Superplasticizers helped reduce these losses by 13 to 18%. These studies show the importance of chlorides in the proposed urea-NaCl solution.

### 2.14.3 Fiber-Reinforced and UHPC Studies

Marcos-Meson et al. (2018) reviewed steel fiber-reinforced concrete and noted that it has better crack resistance and durability. Su et al. (2024) and Ganesh & Murthy (2019) showed that UHPC has superior resistance to chloride ingress. This finding suggests possible uses in biologically aggressive environments. However, no studies have directly examined urea and NaCl exposure in conventional concrete.

### 2.14.4 Studies on Biological Exposures

Limited studies have looked at biological exposures such as urine. Provis (2024) pointed out that wastewater systems see microbiologically influenced corrosion, but there are few studies focused on urine. The chemical makeup of urine, which includes urea and chlorides, implies that there are specific ways it can cause deterioration that other chloride studies do not address. This is why this study concentrates on a simulated urine solution.

### 2.14.5 Studies on Ammonia Compounds and Concrete Performance

Research on ammonia-based compounds offers insight into what occurs when urea breaks down inside or around concrete. Since urea hydrolysis produces ammonia as a main byproduct, understanding how ammonia impacts concrete is important for this study. Aljalawi et al. (2016) looked at how different concentrations of ammonium hydroxide solution affect concrete mixes. They found that low concentrations of ammonia (around 1%) resulted in a slight, mostly insignificant increase in compressive strength. However, higher concentrations led to noticeable reductions, with the largest decrease of about 16.67% recorded at 7 days for the highest ammonia content mix. This shows that ammonia's effect on concrete depends on its concentration. The breakdown products of urea in a curing environment could hinder early-age strength growth.

Further evidence comes from studies on ammonium salts. Research by Ahmad et al. (using ammonium nitrate as a harsh medium) showed that ammonium compounds leach calcium ions from the cement matrix by reacting with calcium hydroxide in the pore solution. This leaching progressively enlarges capillary pores, increases overall porosity, and weakens the cement paste. The studies consistently noted that compressive strength declined and degradation depth increased with longer exposure times. At the same time, the pH of the pore solution also dropped, threatening the protective film around embedded steel. These findings are relevant to the current study because they suggest that urea's hydrolysis products, especially ammonia and carbon dioxide, can lead to pore expansion and pH reduction within the concrete matrix even at fairly low concentrations.

### 2.14.6 Studies on the Effect of Contaminated and Non-Portable Water on Concrete

There is a growing body of research on the use of contaminated or non-portable water, including treated and untreated wastewater, in concrete production and curing. While these studies do not focus directly on urine, they are pertinent because wastewater has many chemical similarities to urine-like solutions, such as dissolved salts, organic compounds, and elevated chloride levels. Asadollahfardi et al. (2021) produced 450 concrete samples using various concentrations of industrial wastewater and examined their compressive strength, tensile strength, water absorption, and electrical resistivity. Their results indicated that industrial wastewater did not significantly change the main properties of concrete at low concentrations. However, higher wastewater concentrations caused uneven decreases in both durability and strength. Critically, curing in secondary wastewater consistently increased water absorption compared to tap water controls, suggesting greater permeability and less resistance to harmful ions.

Hamada et al. (2023) reviewed the broader literature on using wastewater in concrete and confirmed that while treated effluent generally had little negative effect at early stages, secondary and untreated wastewater curing consistently lowered long-term compressive strengths by 9 to 18% beyond 180 days. Additionally, chloride ion penetration increased significantly in wastewater-cured samples compared to fresh water controls. These findings mirror the patterns seen in the current study, where the urea-salt solution produced similar short-term strengths but resulted in lower strength values at 28 days. The similarities between wastewater and urea-salt exposure help contextualize this study's results within the larger framework of contaminated curing environments.

### 2.14.7 Studies on Microbiologically Influenced Corrosion (MIC) in Concrete Infrastructure

Microbiologically influenced corrosion (MIC) is a well-known issue in concrete structures subjected to biological environments. Although this study uses a synthetic chemical solution instead of real urine and does not consider microbial activity, understanding MIC is crucial for contextualizing the real-world conditions this research aims to simulate. Grengg et al. (2024) provided a detailed review of bio-corrosion in concrete sewer systems, concluding that the change of hydrogen sulfide to sulfuric acid by sulfur-oxidizing bacteria is the main cause of concrete damage in wastewater environments. Their review noted that concrete properties, environmental conditions, and wastewater composition all significantly influence corrosion rates, and the lack of standardized test methods for biological exposure remains a major challenge for engineers designing durable sewer infrastructure.

Provis (2024) highlighted that in wastewater systems, microbial activity speeds up the breakdown of organic compounds, producing acids and gases that lower the pH of the surrounding environment and harm the cement matrix. Importantly, Provis noted that bacteria producing urease—the enzyme that breaks down urea, can greatly increase urea hydrolysis when real urine is present, rapidly boosting ammonia production and creating localized pH changes within concrete. This implies that, under real-world conditions, the chemical effects observed in this study using a synthetic solution may be intensified by additional microbial activity, meaning the damage seen in laboratory conditions could be less than what happens in the field. This supports the need for further investigation using real biological fluids.

### 2.14.8 Studies on Protective Coatings and Sealants for Concrete in Aggressive Environments

Since concrete structures in urban areas often face biological contaminants, the use of protective coatings has been studied as a practical solution. Pantazopoulou et al. (as reviewed in Bautista-Gutierrez et al., 2021) documented the historical development and performance of various coating materials applied to concrete exposed to contaminated environments. Their review found that inorganic coatings improved resistance to chloride ion penetration by shifting chloride permeability from high to moderate or low. However, they also noted that some coated samples showed lower resistance to water penetration, suggesting that choosing the right type of coating must match the specific exposure conditions. This is relevant to this study's recommendation that concrete structures in urine-contaminated areas be protected with suitable sealants.

More generally, Bautista-Gutierrez et al. (2021) summarized the main causes of concrete deterioration and reviewed how effective various coating materials are for protecting concrete in contaminated soil and harsh environments. The review concluded that epoxy- and polyurethane-based coatings provided the most consistent protection against both chemical and biological attacks, while cement-based coatings offered more limited protection in environments with organic contamination. These findings support the recommendation in this study that protective surface treatments be applied to concrete elements in areas likely to be exposed to urine, and they provide a basis for future research comparing the performance of different coatings under urea-salt exposure conditions.

### 2.14.9 Studies on the Combined Effect of Multiple Aggressive Agents on Concrete

The literature increasingly recognizes that real-world exposure rarely involves just one harmful agent alone; concrete structures typically encounter a mix of chemical, physical, and biological stresses at the same time. Sun et al. (2015) reviewed durability studies on concrete structures and noted that the combined effect of chlorides and sulfates leads to more serious deterioration than either agent alone. This is because sulfates encourage the formation of expansive secondary compounds like ettringite, while chlorides attack the protective layer on steel. In this study, the urea-salt solution combines urea, which breaks down into ammonia and carbon dioxide, with sodium chloride. This means the concrete specimens faced multiple chemical stresses at once.

Ghanbari and Aslani (2023) similarly showed that combined chloride-sulfate attack speeds up corrosion-induced cracking more than single-agent exposure, significantly reducing predicted service life. While their study focused on marine environments, the principle also applies to any situation where multiple dissolved species are present in the curing or exposure medium.

This evidence supports the theoretical framework of this study's design. By combining urea with sodium chloride in the simulated urine solution, the experiment more accurately replicates the multi-agent nature of real biological exposure than a single-compound study would. It also helps explain why the strength reduction seen in the urea-salt specimens at 28 days was more significant than expected from either chloride or urea exposure alone.

### 2.14.10 Studies on Carbonation and pH Reduction in Concrete Under Chemical Exposure

Carbonation, which is the process where atmospheric or dissolved carbon dioxide reacts with calcium hydroxide in the cement paste to lower its pH, is closely linked to the degradation mechanisms triggered by urea exposure. When urea hydrolyzes, carbon dioxide is one of the products released. This means that prolonged exposure to a urea-based solution could speed up localized carbonation within the concrete pore structure, reducing the pH of the pore solution and endangering the protective film around embedded steel. Cao et al. (2019) confirmed that when carbonation lowers the pore solution pH to below 9, the passive oxide film on steel becomes unstable, leading to pitting corrosion even without chlorides. Their work also noted that the critical chloride threshold drops significantly as pH decreases, suggesting that the combination of urea-induced carbonation and chloride ions from NaCl in this study's solution could create conditions considerably more harmful than either factor alone.

Papadakis (1999), whose research on organic acid attack is one of the few directly relevant studies, showed that compounds chemically similar to those produced during urea hydrolysis can react with calcium silicate hydrate gel, progressively breaking down the strongest component of the hardened cement paste. This microstructural weakening increased porosity over time, allowing for more aggressive ions to enter in a self-reinforcing cycle of deterioration.

These findings are consistent with the pattern observed in this study, where the urea-salt specimens showed a slight but clear strength reduction between 14 and 28 days, suggesting ongoing microstructural attack rather than a one-time initial reaction.

### 2.15 Research Gap

The literature shows a notable gap in understanding the effects of urea-based solutions, especially those that mimic urine, on reinforced concrete and steel reinforcement. Gürten et al. (1993) studied urea as a de-icer, but their research did not cover biological fluids. The combined effects of urea and chlorides in urine-like conditions have not been explored. Chloride-induced corrosion is well-documented (Akinsola et al., 2012; Jassam et al., 2020), but urine's unique chemical makeup, which includes urea, ammonia, and organic compounds, brings specific challenges that past studies have not addressed. The impact of urea–NaCl solutions on the tensile strength of steel reinforcement is especially under-researched, as most studies focus solely on chloride-induced corrosion. The lack of standard testing methods for biological exposures hampers efforts to design durable structures in areas susceptible to urine contamination, like urban infrastructure. This study aims to fill these gaps by carefully evaluating the compressive strength of concrete and the tensile strength of steel under controlled urea–NaCl exposure. It will provide baseline data for designing and maintaining infrastructure in biologically aggressive settings.

# CHAPTER THREE

# METHODOLOGY

## 3.1 Materials

### 3.1.1 Cement

Ordinary Portland Cement (OPC), conforming to ASTM C150 and NIS 444-1, was used as the binder and was sourced from a commercial supplier within Benin City to ensure standardized composition and quality.

*Figure 3.1: Ordinary Portland Cement (OPC)*

### 3.1.2 Fine and Coarse Aggregates

Clean, well-graded river sand was used as the fine aggregate, and crushed granite (12–20 mm size) served as the coarse aggregate. Both conforming to ASTM C33. Both materials were procured from a local supplier in Benin City.

*Figure 3.2: Fine aggregate and coarse aggregate (crushed granite)*

### 3.1.3 Water

Potable Ttap water was sourced from the Civil Engineering laboratory at the University of Benin.

### 3.1.4 Urea and Sodium Chloride (NaCl)

Technical-grade urea was purchased from a certified chemical supplier in Benin City and sodium chloride (salt) was purchased from a local store. Both materials were used to formulate the urea–salt curing solution.

*Figure 3.3: Technical grade urea and sodium chloride (salt)*

## 3.2 Concrete Mix Design

The concrete was designed using a nominal mix ratio of 1:2:4 (cement: sand: granite) with a water–cement ratio of 0.5, targeting Grade 25 concrete.

## 3.3 Casting of Specimens

Twenty (20) concrete cubes, each measuring 100 mm × 100 mm × 100 mm, were cast. The concrete was mixed thoroughly and poured into lubricated steel moulds in three layers, each layer compacted on a vibrating table to eliminate air voids. After 24 hours, the cubes were demoulded.

### 3.4 Preparation of Urea–Salt Curing Solution

The simulated urine solution was made by dissolving 10 g of crystalline urea and 2 g of NaCl in 1 liter of water. The cubes were completely submerged in the curing media and kept at room temperature.

### 3.5 Curing Procedure

Curing was carried out as follows:

a. 5 cubes cured in fresh water for 14 days
b. 5 cubes cured in fresh water for 28 days
c. 5 cubes cured in urea-salt solution for 14 days
d. 5 cubes cured in urea-salt solution for 28 days

All samples were labeled accordingly and kept in clean, covered containers at room temperature.

### 3.6 Testing Procedures

#### 3.6.1 Compressive Strength Test

After the designated curing periods, the cubes were removed, surface-dried, and tested using a compression testing machine in accordance with ASTM C39. The maximum load at failure (P) was recorded, and compressive strength ($f_c$) was calculated using:

$$f_c = \_ \tag{3.1}$$

Where:

$f_c$ = compressive strength (N/mm²)

P = Maximum load at failure (N)

A = cross sectional area of the cube (mm²)

### 3.6.2 Visual Surface Inspection

Each cube was visually inspected for surface discoloration, cracking, or scaling before and after curing.

## 3.7 Data Analysis

The average compressive strength values for each group were calculated and compared across the curing media and durations.

Since experimental testing was conducted only at 14 and 28 days, compressive strength values at 7 and 21 days were estimated using linear interpolation between these two measured data points, in order to provide a more complete picture of strength development over the curing period. These interpolated values are clearly identified as such in the results and were used solely for graphical illustration purposes; all conclusions drawn in this study are based on the experimentally obtained 14-day and 28-day results.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Results

The experiment had four distinct curing groups to evaluate the impact of the urea-salt solution on compressive strength at two different ages. The first group included five concrete cubes cured in fresh water for 14 days. These cubes acted as the early-age control, establishing a baseline for what typical cement hydration achieves in the short term under ideal conditions. The second group also had five cubes cured in fresh water, but for 28 days. This group served as the late-age control, confirming that curing in fresh water supports ongoing strength development over time, consistent with known concrete behavior.

The third group comprised five cubes cured in the urea-salt solution for 14 days. Comparing this group directly with the first allowed us to isolate the early-age effect of urea-salt exposure against fresh water. The fourth group consisted of five cubes cured in the urea-salt solution for 28 days. This group was crucial to the study's goals, as it showed the cumulative effect of prolonged chemical exposure on compressive strength development. The average compressive strength values from these four groups are shown and compared in Table 4.1.
The compressive strength values for 7 and 21 days were obtained using linear interpolation based on the 14 and 28 day experimental results and their average compressive strength values are also shown Table 4.1.

**Table 4.1 Compressive Strength of Concrete Cubes Cured in Fresh Water and Urea-Salt Solution at 7, 14, 21 and 28 days**

| COMPRESSIVE STRENGTH (N/mm$^2$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | FRESH WATER SAMPLE | | | | UREA-SALT SOLUTION | | | |
| **CUBE** | **7 days** | **14 days** | **21 days** | **28 days** | **7 days** | **14 days** | **21 days** | **28 days** |
| **1** | 18.85 | 20.95 | 23.06 | 25.16 | 4.52 | 10.63 | 16.75 | 22.86 |
| **2** | 21.66 | 22.96 | 24.27 | 25.57 | 28.71 | 24.01 | 19.32 | 14.62 |
| **3** | 10.26 | 13.52 | 16.79 | 20.05 | 18.75 | 17.29 | 15.84 | 14.38 |
| **4** | 25.79 | 25.34 | 24.89 | 24.44 | 12.89 | 15.82 | 18.75 | 21.68 |
| **5** | 24.60 | 23.27 | 21.95 | 20.62 | 26.76 | 23.01 | 19.27 | 15.52 |
| **Average** | **20.23** | **21.21** | **22.19** | **23.17** | **18.32** | **18.15** | **17.99** | **17.81** |

## 4.2 Graphical Analysis of Compressive strength

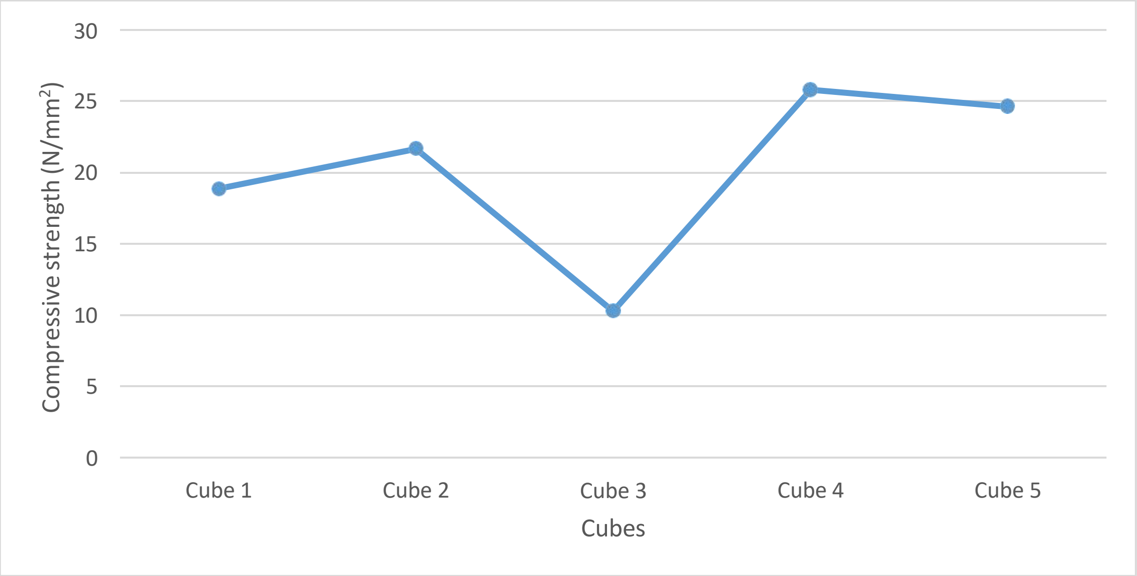

**Figure 4.1:** Compressive strength of concrete at 7 days (Fresh Water)

From figure 4.1, the extrapolated 7-day compressive strengths for fresh water-cured specimens show a lot of variability across the five cubes. Cube 4 and Cube 5 have the highest early-age strengths, while Cube 3 has the lowest at 10.26 N/mm². This variation is common at early ages; small differences in compaction, water distribution, and demoulding can significantly impact the results before full hydration occurs. The average of 20.23 N/mm² serves as a reasonable early-age baseline for Grade 25 concrete cured under ideal conditions.

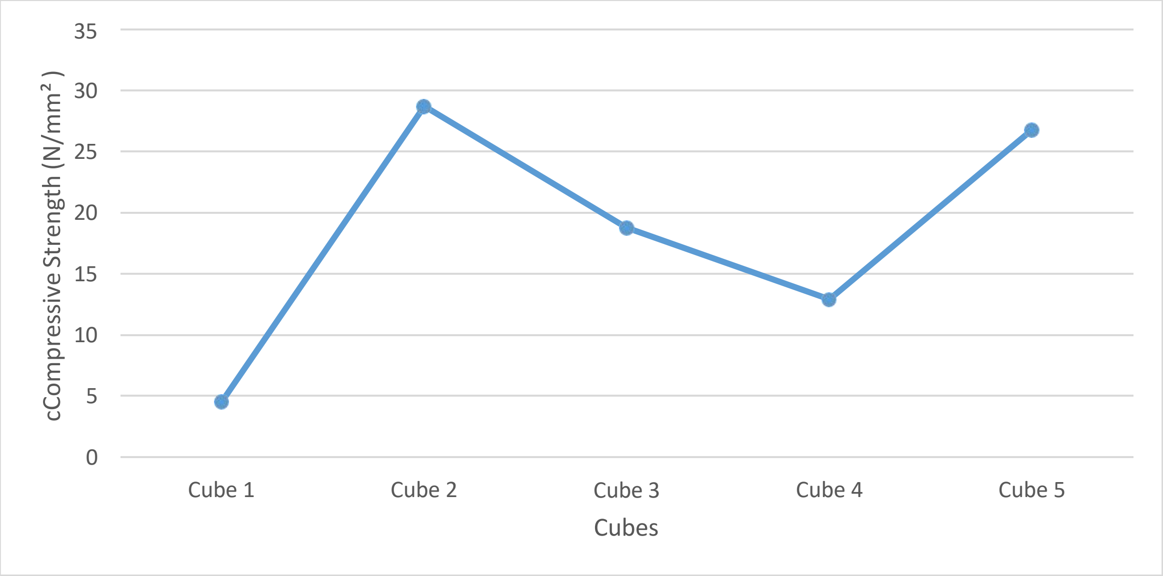

**Figure 4.2:** Compressive strength of concrete at 7 days (Urea-Salt Solution)

From figure 4.2, the extrapolated 7-day values for the urea-salt group show the widest spread of all groups in this study. Cube 1 has an extremely low value of 4.52 N/mm², while Cube 2 registers the highest at 28.71 N/mm². This high variability likely results from the extrapolation method; early-age values are especially sensitive to changes between 14 and 28 days. Cubes that had declining strength over time, like Cube 2, produce inflated extrapolated 7-day values. Still, the group average of 18.32 N/mm² is comparable to the fresh water group at the same age, indicating that the urea-salt solution has not yet significantly affected hydration at early stages.

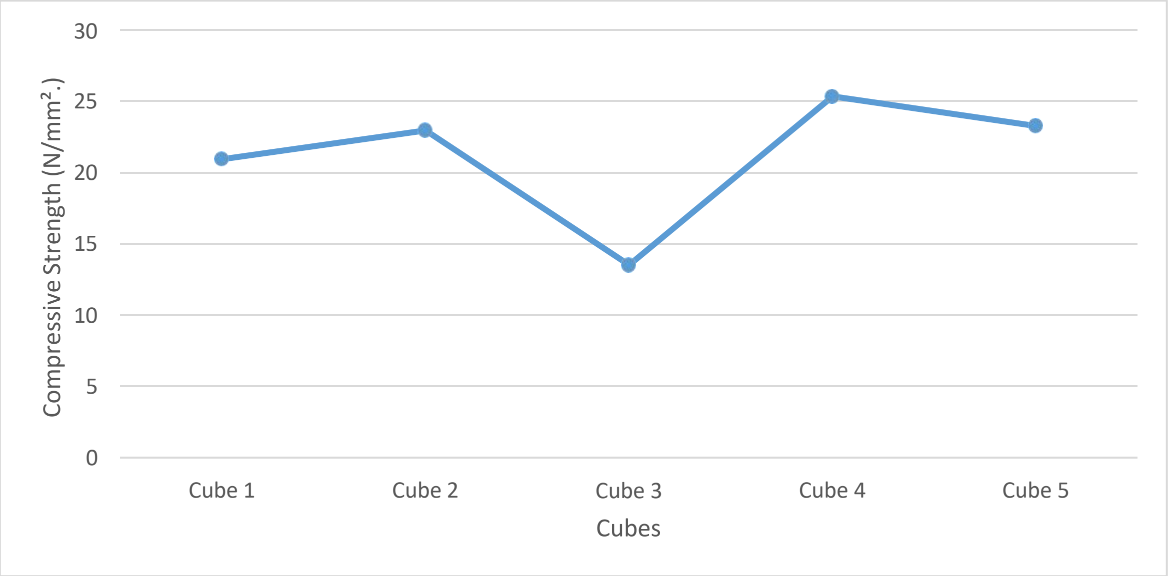

**Figure 4.3:** Compressive strength of concrete at 14 days (Fresh Water)

From figure 4.3, by 14 days, the fresh water-cured specimens still show variability at the individual cube level, but the spread is more moderate than at 7 days. Cube 3 remains the weakest in this group, while Cube 4 has the highest strength. Since these are actual experimental values, the average of 21.21 N/mm² confirms an early-strength benchmark. The results align with expectations for a 1:2:4 mix cured under standard conditions, where significant hydration has occurred but is not yet complete.

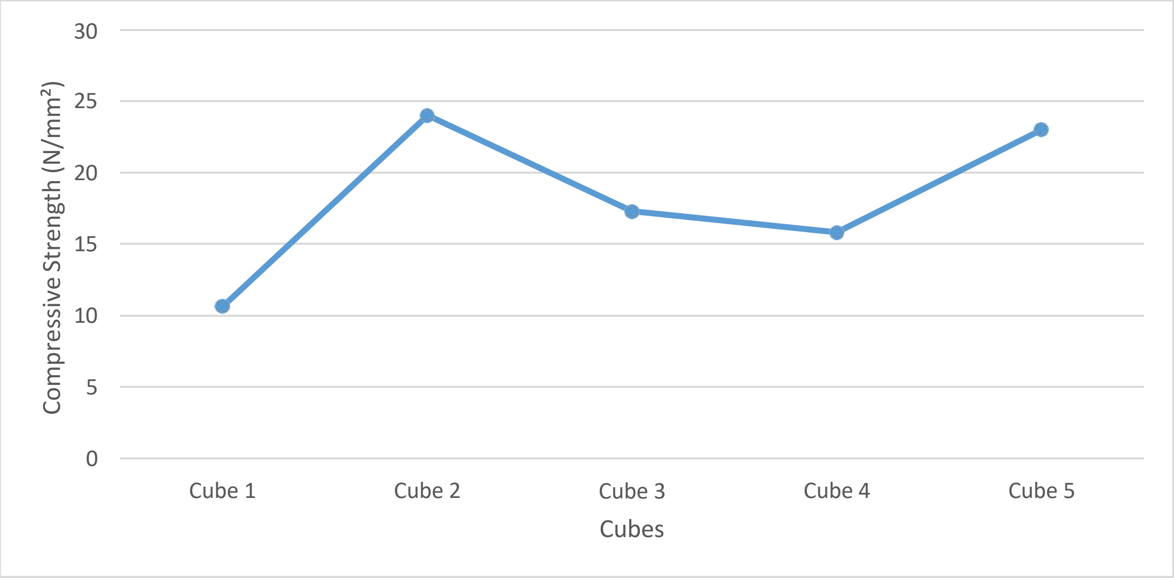

**Figure 4.4:** Compressive strength of concrete at 14 days (Urea-Salt Solution)

From figure 4.4, at 14 days, the urea-salt cured specimens show a wide range of individual strengths. Cube 1, at 10.63 N/mm², is notably weak, while Cube 2 reaches 24.01 N/mm². The average of 18.15 N/mm² is only slightly below the fresh water average at the same age, indicating that the harmful effects of the urea-salt solution are still relatively limited in the early stages of curing. However, the wider variation among cubes suggests that the chemical environment is starting to create inconsistencies in the hydration process.

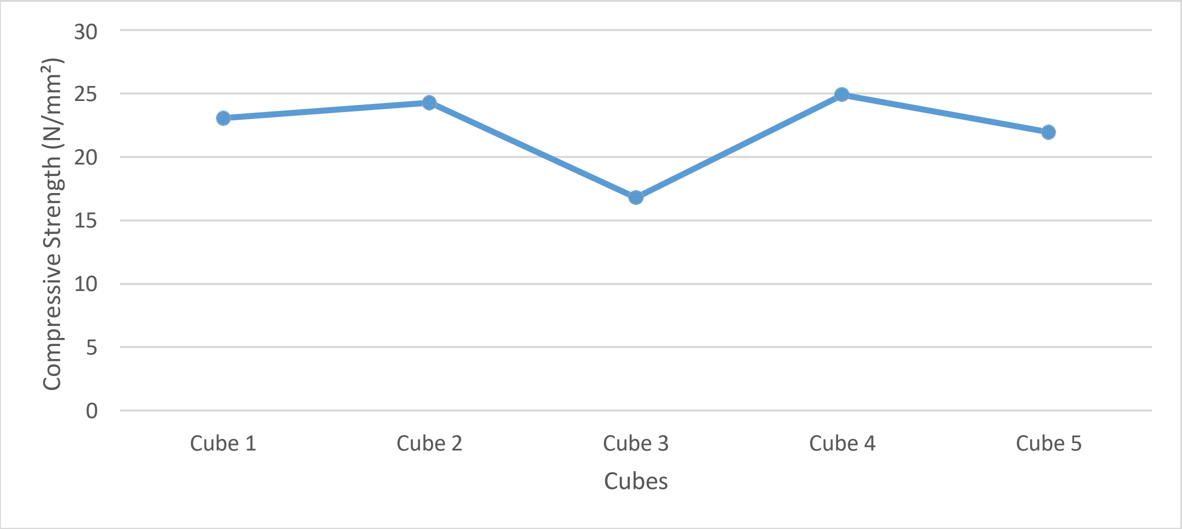

**Figure 4.5:** Compressive strength of concrete at 21 days (Fresh Water)

From figure 4.5, The interpolated 21-day values for fresh water specimens show a clear upward trend from the 14-day results for most cubes. The average rises to 22.19 N/mm², which is midway between the 14-day and 28-day averages, as expected from linear interpolation. Cube 3 remains the weakest across all time points, but even it shows consistent improvement over time. This pattern confirms that fresh water curing supports steady strength gain, allowing hydration to progress effectively.

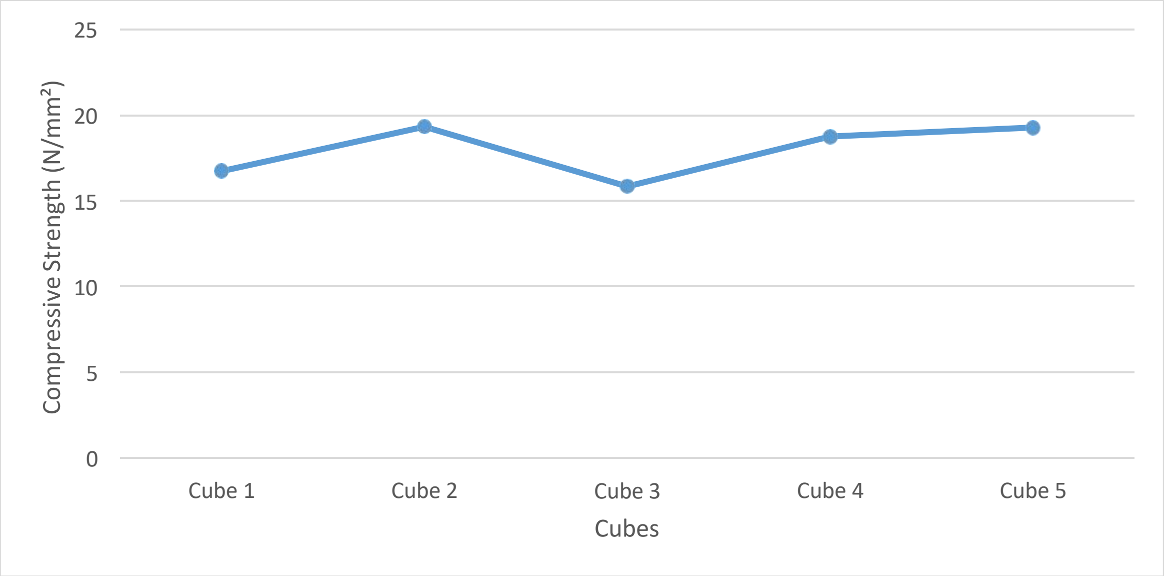

**Figure 4.6:** Compressive strength of concrete at 21 days (Urea-Salt Solution)

From figure 4.6, In contrast to the fresh water group, the 21-day interpolated values for the urea-salt specimens show little to no improvement over the 14-day results, and the group average of 17.99 N/mm² is nearly unchanged from the 14-day average of 18.15 N/mm². Notably, individual cubes that had higher strengths at 14 days, such as Cubes 2 and 5, decrease by 21 days, while Cube 1 shows an increase. This difference in behavior for individual cubes indicates that the urea-salt solution disrupts the uniformity of the hydration process. The stagnation in average strength at this stage suggests early signs of deterioration that become clearer by 28 days.

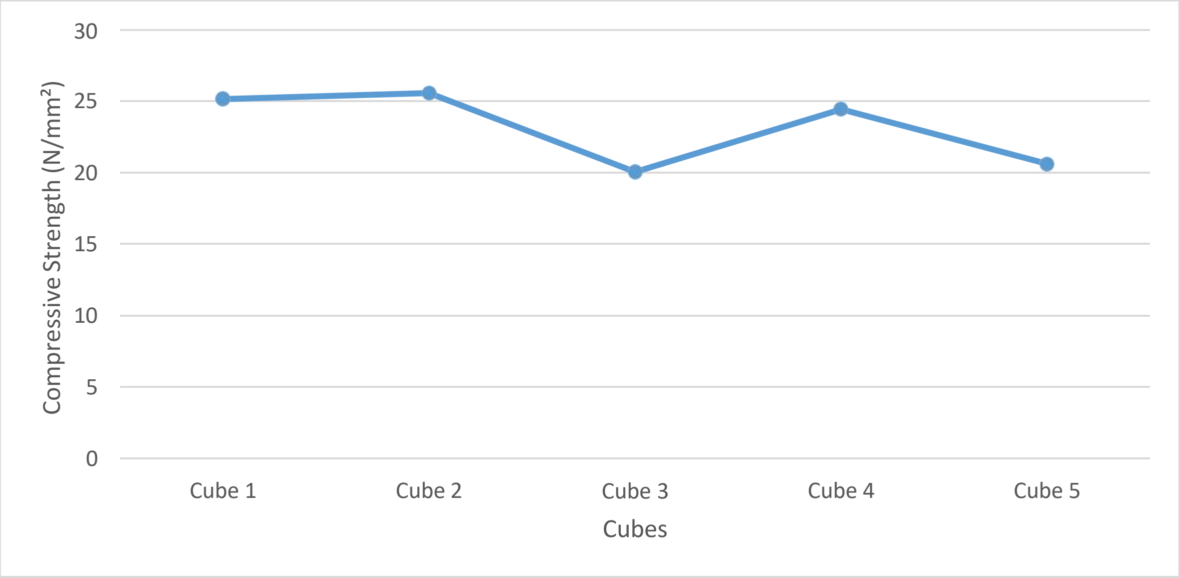

**Figure 4.7:** Compressive strength of concrete at 28 days (Fresh Water)

From figure 4.7, by 28 days, the fresh water group reaches its highest average compressive strength of 23.17 N/mm², marking an increase of about 23% over the 14-day average. The individual cube values cluster more closely than at earlier ages, with most falling between 20 and 26 N/mm². This narrowing reflects the continued progress of cement hydration under ideal curing conditions. The 28-day result confirms that the mix design and curing procedure are effective for achieving Grade 25 concrete performance.

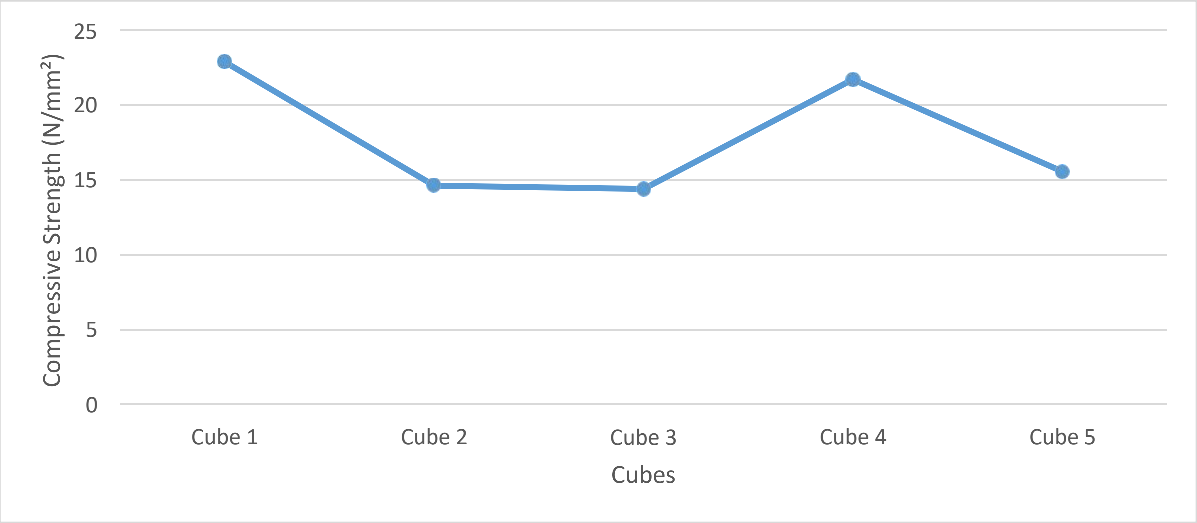

**Figure 4.8:** Compressive strength of concrete at 28 days (Urea-Salt Solution)

From figure 4.8, the 28-day results for the urea-salt group provide the most significant insight of this study. Instead of gaining strength, the group average slightly drops from 18.15 N/mm² at 14 days to 17.81 N/mm² at 28 days — a decrease of about 1.87%. At the individual cube level, Cube 2 falls sharply from 24.01 N/mm² at 14 days to 14.62 N/mm², and Cube 3 declines as well. Only Cube 1 shows a notable improvement. This trend indicates that by 28 days, the cumulative chemical effects from urea hydrolysis byproducts and chloride ions disrupt strength development. The chemical interactions, such as the reaction between urea breakdown products and calcium hydroxide in the cement paste and the crystallization pressure from sodium chloride in the pore structure, seem to weaken the microstructure with prolonged exposure.

### 4.3 Discussion of Results

The results from this study show clear differences in how concrete cured in fresh water compares to concrete cured in a urea and salt solution over time. Concrete cured in fresh water consistently increased in compressive strength from 7 to 28 days. This pattern is typical for normal concrete because continuous hydration creates more calcium silicate hydrate (C-S-H) gel, which leads to greater strength and less porosity.

On the other hand, concrete cured in the urea and salt solution showed uneven strength development. Some initial strength appeared in the early curing stages, but the overall trend showed stagnation and eventual decline in compressive strength as curing time increased. This suggests that urea and salt ions disrupt the hydration process and damage the internal structure of the concrete.

The drop in strength seen in the urea and salt samples may result from several factors. These include higher permeability, chemical reactions between harmful ions and cement hydration products, and possible formation of microcracks in the concrete. These issues become more noticeable with longer exposure, as seen in the results at 21 days and 28 days.

Moreover, the variability in the urea and salt results shows that the curing environment causes instability in strength development, making the concrete less reliable for structural use. In contrast, the results from fresh water curing are relatively uniform, demonstrating stability and predictability.

Overall, the findings confirm that while fresh water curing improves concrete strength and durability, exposure to the urea and salt solution negatively affects both short-term and long-term performance. This underscores the need to protect concrete structures from biologically and chemically harmful environments to maintain their integrity and lifespan.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

This study evaluated the effect of curing reinforced concrete in a urea-salt (simulated urine) solution compared to curing in fresh water, with emphasis on the compressive strength development of the concrete cubes. By comparing concrete cubes cured in fresh water and urea–salt solution, the study was able to assess the impact of a biologically active curing environment on cement hydration and overall concrete performance. The results obtained contribute to addressing the lack of data on the behavior of concrete under such unconventional exposure conditions. Based on the analysis of the experimental results, the following conclusions were drawn:

a. Concrete cured in fresh water showed a normal increase in compressive strength with age, from 18.81 N/mm² at 14 days to 23.17 N/mm² at 28 days, indicating a strength gain of approximately 23%. This confirms that fresh water curing provides a favorable environment for cement hydration and continuous strength development.
b. In contrast, concrete cured in urea-salt solution experienced a slight reduction in compressive strength over time, averaging 18.15 N/mm² at 14 days and 17.81 N/mm² at 28 days, representing a strength loss of approximately 1.87%. This suggests that prolonged exposure to urea–salt environments may negatively affect the hydration process and strength development of concrete.
c. Based on the findings of this study, prolonged exposure of concrete to urea–salt or similar chemically and biologically contaminated environments may compromise concrete performance. Therefore, concrete elements in such environments may

experience reduced durability if appropriate preventive or protective measures are not implemented.

## 5.2 Recommendations

Based on the findings and conclusions of this study, the following recommendations are made to engineers, facility managers, policymakers, and relevant stakeholders involved in the design, construction, and maintenance of concrete structures:

a. Avoid exposure to urea-contaminated environments:
b. Concrete structures located in areas prone to urine contamination (e.g., public spaces, animal enclosures) should be regularly cleaned and protected.
c. Protective coatings or sealants should be applied to reduce penetration of aggressive agents into the concrete.
d. Further research should be conducted to assess the microstructural changes and chemical reactions caused by urea and salts on cement hydration.
e. Field studies should also be carried out to confirm these laboratory findings under real environmental conditions.

## 5.3 Suggestions for Further Research

Although this study provides useful insight into the effect of urea–salt exposure on the compressive strength of concrete, it was limited in scope, duration, and testing parameters. Further research is therefore necessary to build upon the findings of this work and enhance understanding of concrete behavior under biological exposure conditions. Future studies may consider the following areas:

a. Investigating the effect of real urine exposure on reinforced concrete, to compare its chemical aggressiveness and impact on strength and durability with the simulated urea–salt solution used in this study.

b. Assessing the corrosion behavior of embedded steel reinforcement under urea or urine exposure, including its effect on tensile strength and bond performance.

c. Conducting microstructural and chemical analyses (e.g., SEM or XRD) to understand the reaction mechanisms between urea, chloride ions, and cement hydration products.

d. Extending the curing and exposure duration beyond 28 days to observe long-term effects of biological and chemical contamination on concrete.

e. Exploring protective coatings or admixtures that can reduce deterioration caused by urea or chloride-rich environments.

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# APPENDIX

**Plate A-1:** Mixing of materials for concrete preparation