THE POTENTIAL OF EPOXY COATED CHICKEN FEATHERS AS MODIFIED NATURAL FIBER IN CONCRETE

By

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SUMMARY

This study assessed the viability of incorporating both untreated (UCF) and treated chicken feathers (TCF) into concrete to enhance sustainability in the construction industry. Five concrete mixes were tested, with Mix 4 (0.75% TCF) and Mix 5 (1.25% TCF) emerging as the most promising. These mixes showed improved workability and retained high compressive and tensile strength compared to the control. In contrast, the mix with 1% UCF exhibited significant reductions in mechanical and durability performance. Durability tests confirmed that TCF-enhanced concrete maintained resistance to oxygen permeability, water absorption, and chloride penetration, while also displaying reduced shrinkage. Overall, treated feathers proved to be a suitable partial replacement in non-structural concrete applications, offering both environmental and engineering benefits.

KEY TERMS:

Chicken Feathers (CF); Untreated Chicken Feathers (UCF); Treated Chicken Feathers (TCF); Sustainability; Workability; Compressive Strength; Tensile Strength; Durability; Shrinkage; Non-Structural Applications

DEDICATION

First and foremost, to God:

Thank You for being my source of wisdom, strength, and grace. This journey would not have been possible without Your guiding hand, divine favor, and constant presence.

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ABSTRACT

The disposal of chicken feathers (CF), a byproduct of the poultry industry, poses significant environmental challenges due to their non-biodegradable nature. This study investigates the feasibility of incorporating both untreated (UCF) and treated chicken feathers (TCF) as partial replacements in concrete by mass to promote sustainability and reduce waste. Five concrete mixes were prepared: Mix 1 – 0% CF (control), Mix 2 – 1% UCF, Mix 3 – 1% TCF, Mix 4 – 0.75% TCF, and Mix 5 – 1.25% TCF.

Workability, assessed through slump tests, showed that Mix 4- 0.75% TCF achieved the highest slump value of 60 mm, compared to 55 mm for Mix 1- 0% CF and Mix 2- 1% UCF, indicating improved workability at moderate TCF levels. However, increasing TCF content to 1.25% (Mix 5- 1.25% TCF) reduced slump to 40 mm, suggesting diminished workability at higher feather volumes.

Mechanical testing revealed that at 28 days, Mix 1- 0% CF attained a compressive strength of 72.13 MPa, while Mix 4- 0.75% TCF and Mix 5- 1.25% TCF recorded slightly lower strengths of 65.50 MPa and 67.22 MPa respectively (approximately 9% reduction). Mix 2- 1% UCF exhibited a significant strength loss, achieving only 48.58 MPa (about 33% lower). Tensile strength tests at 90 days showed a similar trend: Mix 1- 0% CF reached 8.47 MPa, Mix 2- 1% UCF dropped drastically to 4.75 MPa, whereas the TCF mixes (Mix 3- 1% TCF, Mix 4- 0.75% TCF, Mix 5- 1.25% TCF) ranged between 6.42 MPa and 7.54 MPa, approaching the control values.

Durability assessments, including Oxygen Permeability Index (OPI), sorptivity, and chloride conductivity tests conducted over 28, 56, and 90 days, indicated that TCF mixes (Mix 3- 1% TCF, Mix 4- 0.75% TCF, Mix 5- 1.25% TCF) maintained good to excellent resistance to oxygen permeability, water absorption, and chloride penetration—comparable to the control. In contrast, Mix 2- 1% UCF demonstrated poor performance across these durability parameters, highlighting the importance of feather treatment for concrete compatibility.

Shrinkage behavior was evaluated across all mixes, yielding consistent and reliable results. Average shrinkage values ranged from 0.0138 to 0.0371, with the highest

shrinkage observed in Mix 2- 1% UCF and the lowest in Mix 5- 1.25% TCF, further confirming the dimensional stability and improved performance of treated feather-incorporated concretes. This study demonstrates that Mix 4- 0.75% TCF and Mix 5- 1.25% TCF, can be successfully used in non-structural concrete applications with minimal compromise in mechanical strength and enhanced durability.

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GLOSSARY- TERMS AND CONCEPTS

Term	Definition
Chicken Feathers (CF)	A byproduct of the poultry industry, considered for use as a partial replacement in concrete mixes.
Untreated Chicken Feathers (UCF)	Chicken feathers used in concrete without any chemical or physical modification.
Treated Chicken Feathers (TCF)	Chicken feathers that have undergone a treatment process to improve their compatibility with concrete.

CHAPTER 1

1.1 Background

Concrete, comprising cement, aggregates (commonly stones and sand), and water, stands as the most extensively utilized construction material globally (Gagg, 2014). This combination yields a durable and adaptable building material, playing a foundational role in various structures within the construction industry.

Concrete has high compression strength, which makes it perfect for creating strong foundations for bridges, buildings and skyscrapers, to mention a few. Its flexibility lets it form into different shapes and dimensions making it serve different construction needs. Cement is a key component of traditional concrete. It is a fine powder that acts as a binder, holding the aggregates together. The most used type of cement is ordinary Portland cement (OPC), which is made by heating limestone and clay in a kiln. Concrete possesses the property of being robust when subjected to compression but relatively weaker when subjected to tension (Windisch, 2021). Therefore, there is a need to enhance its tensile strength.

Introduction of fiber in concrete has been suggested over the years as the promising solution to enhance the tensile strength of concrete (Abousnina et al., 2021). Besides improving tensile strength, fibers are also reported to improve compressive strength, elastic modulus, crack resistance, crack control, durability, fatigue life, resistance to shock loads, resistance to abrasion, shrinkage, thermal characteristics and fire resistance (Koniki and Prasad, 2019).

In concrete mixtures, two main categories of fibers are commonly utilized: synthetic fibers, which include materials like steel, polymers, and glass, and natural fibers, such as coconut fiber, straw, cotton, and bamboo (Verma and Ahirwar, 2017). Synthetic fibers, like steel fibers, enhance tensile strength and durability by effectively controlling cracking caused by shrinkage and thermal stresses (Garg et al., 2021). Polymeric fibers, derived from materials like polypropylene or polyester, improve impact resistance and toughness, while glass fibers, known for their lightweight properties, boost flexural strength and corrosion resistance (Altalabani et al., 2020). Natural fibers, including coconut, straw, cotton, and bamboo, provide unique benefits such as increased ductility, reduced concrete weight, and environmentally friendly characteristics. The choice between synthetic and natural fibers depends on specific project requirements, cost considerations, and environmental factors.

Natural fibers such as chicken feathers have physicochemical and mechanical characteristics that can be used in the development of fiber concrete (Araya-Letelier et al., 2020). Chicken feathers are insoluble in organic solvents, eco-friendly, renewable, non-abrasive, biodegradable, low density, hydrophobic behaviour, ability to dampen sound, warmth retention and cost effective (Tesfaye et al., 2018).

Globally, the poultry industry generates millions of tons of chicken feathers each year, creating significant environmental challenges if not managed properly. In South Africa, large-scale poultry production produces thousands of tons of feather waste annually, which are often underutilized or disposed of in landfills. This highlights the opportunity to convert such waste into valuable resources for sustainable construction materials. Moreover, as the construction sector increasingly seeks environmentally friendly alternatives, there is a growing local market demand for affordable, lightweight, and eco-friendly reinforcement materials that can supplement or replace traditional synthetic fibers.

Natural fibers are sensitive to changes in moisture content, and they suffer deterioration or petrification due to the alkaline environment and the continuous cement hydration (Wei and Meyer, 2014). This represents a research gap that triggers a need to be addressed through a search of suitable materials to protect them from deterioration or petrification.

To bridge the gap on deterioration or petrification of natural fibers, this study aimed to utilize epoxy coated chicken feathers as modified natural fiber in concrete. The overarching objective of this study holds significant importance as it seeks to provide insights into the feasibility and effectiveness of utilizing epoxy coated chicken feathers as reinforcing fibers in the construction industry. Furthermore, this study represents a pioneering and innovative approach, offering new perspectives and practical solutions, thereby advancing sustainable and resilient construction materials and methodologies.

1.2 Problem Statement

Most traditional concretes are reported to have good compressive strength but have weak tensile strength. To overcome this weakness, researchers have been using various materials such as natural fibers as fiber reinforcements. However, natural fibers are reported to be prone to degradation or becoming rigid in response to fluctuations in moisture levels and exposure to an alkaline environment caused by ongoing cement hydration (Sutarno et al., 2021).This limitation highlights a research gap that calls a need to be researched.

Paying heed to the above problem, this study aimed to address the degradation of natural fibers in concrete, taking a case study of utilizing chicken feathers. Chicken feathers as natural fibers in concrete are reported to suffer from degradation which results into a poor concrete performance. In this study, chicken feathers were treated with epoxy resin as a coating to prevent them from degradation. Both concrete samples without chicken feathers and those with untreated chicken feathers were employed as control samples. The study's overall outcomes carry significant implications for various sectors, including the construction, environment, and economy, thereby contributing to a range of sustainable development goals.

Chicken feathers were chosen as a material of interest due to their high availability as a byproduct of the poultry industry, low density, biodegradability, and potential to enhance the mechanical and durability properties of concrete in a cost-effective and sustainable manner.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this research was to investigate the potential of epoxy coated chicken feathers as modified natural fiber in concrete. To attain this aim, specific objectives were set as outlined in section 1.3.2.

1.3.2 Objectives

The objectives of this study are:

i. To determine the physical properties of the fine aggregate and coarse aggregate used in the study.
ii. To design a concrete mix with a target compressive strength using fine aggregate, coarse aggregate, cement, water, and untreated/treated/without chicken feathers based on the Cement and Concrete Institute (C & CI) method.
iii. To cast concrete using the designed mix proportions of fine aggregate, coarse aggregate, cement, water, and untreated/treated/without chicken feathers.
iv. To assess the performance of the cast concrete without feathers, with untreated feathers, and with treated feathers in terms of workability, mechanical, and durability properties.
v. To establish the statistical relationship between dependent and independent variables related to the performance of concrete without feathers, with untreated feathers, and with epoxy coated chicken feathers.

1.4 Research Questions

This study was guided by the following research questions:

i. What are the physical properties of fine aggregate and coarse aggregate used under this research?
ii. What is the amount of fine aggregate, coarse aggregate, cement, water and untreated/treated /without chicken feathers required for the casting of concrete based on the Cement and Concrete Institute (C & CL) method?
iii. How is concrete cast using the optimized amount of fine aggregate, coarse aggregate, cement, water and untreated/treated/without chicken feathers?
iv. What is the performance of the cast concrete without feathers, with untreated feathers, and with treated feathers in terms of workability, physical-mechanical, and durability properties?
v. What is the statistical relationship between dependent and independent variables related to the performance of concrete without feathers, with untreated feathers, and with epoxy coated chicken feathers?

1.5 Significance of the Research

The study’s scope encompassed a comprehensive exploration of utilizing epoxy-coated chicken feathers as modified natural fibers in concrete, targeting several critical aspects. It aimed to investigate the impact of these modified fibers on various properties of concrete, including workability, tensile strength, compressive strength, and durability. Additionally, the study aimed to conduct a comparative evaluation between traditional concrete, concrete with untreated feathers, and concrete with epoxy-coated feathers to determine the efficacy of modified fibers in improving concrete's mechanical and durability properties.

By delving into the degradation issues of natural fibers and assessing the efficacy of epoxy-coated chicken feathers in enhancing concrete properties, this study aimed to offer new insights and practical solutions for developing sustainable, durable, and resilient construction materials. The findings are intended to significantly contribute to advancing the knowledge base in construction engineering and materials science, striving to create more robust and eco-friendly construction solutions for various industry applications.

1.6 Scope and Limitation

The research aimed to address a critical gap in construction materials by focusing on the degradation and petrification challenges encountered by natural fibers, particularly chicken feathers, when incorporated into concrete. By introducing epoxy-coated chicken feathers as modified natural fibers in concrete, this study aimed to provide a pioneering solution to safeguard these fibers from moisture-induced deterioration and the alkaline environment resulting from cement hydration.

One significant aspect of this study is its commitment to sustainable material development. Investigating the use of epoxy-coated chicken feathers as reinforcing agents aligns with global sustainability goals by repurposing waste materials and reducing environmental impact. This approach offers an eco-friendly, renewable, and cost-effective solution that could contribute to sustainable construction practices. Moreover, the study introduced an innovative methodology for modifying natural fibers for use in construction materials.

In a nutshell, the use of epoxy-coated chicken feathers presents a novel and practical solution that expands the possibilities of employing unconventional yet effective materials in the construction industry. This innovation has the potential to influence and revolutionize construction methodologies by offering a unique protective solution for natural fibers. Fundamentally, this approach advocates for the principles of recycling, reusing, and minimizing waste.

While this study provides valuable insights into the use of epoxy-coated chicken feathers as reinforcement in concrete, several limitations should be noted. Only epoxy-coated feathers were investigated, and other treatment methods were not explored. The study focuses on non-structural concrete applications, and results may not be directly applicable to structural concrete. Testing was conducted under controlled laboratory conditions, which may not fully represent field environments. Additionally, only specific feather contents were examined, and long-term durability under environmental exposure was not assessed. The delimitations of the study include the intentional focus on non-structural concrete and selected feather treatments and proportions, which define the scope of the research. The study is conducted under certain assumptions, including that the aggregates are of consistent quality, the concrete curing process follows standard procedures, and the epoxy coating uniformly covers the chicken feathers. These assumptions ensure consistency and reliability in experimental results.

1.7 Dissertation Structure

Chapter 1; provides the foundational introduction to the study, setting the stage for the research that follows.

Chapter 2; delves into the comprehensive literature review, examining prior and pertinent works that form the backdrop for the current study. A detailed review was conducted to examine the feasibility of integrating chicken feathers as a natural fiber within concrete. This review aimed to explore the potential role of chicken feathers as a natural fiber additive in concrete. The objectives and significance of this study were derived from the insights gathered during this review.

The review process involved utilizing keyword searches and Boolean operators to source relevant articles from reputable platforms such as Science Direct, Google Scholar, and dedicated editorial websites. The primary focus was to understand the application of chicken feathers as a natural fiber in concrete and analyze their impact on the properties and behavior of the material.

This chapter encompasses various sections that delve into the role of chicken feathers as a natural fiber in concrete, investigating their compatibility and effects on the characteristics of concrete.

Chapter 3; outlines the meticulously planned methodology employed to fulfil the study's defined objectives. This chapter covers the various experiments conducted, adhering to established standards, encompassing aspects such as sample preparation, the casting of reinforced concrete, and a battery of tests, including compressive strength, durability, tensile strength, and dry shrinkage.

Chapter 4; presents the substantive results of the conducted experiments, coupled with an in-depth analysis of the obtained data. This chapter further engages in detailed explanations and discussions of the results, while also making comparisons with findings from related research conducted by various scholars within similar domains.

Chapter 5; serves as the culmination of the dissertation, offering conclusive insights and recommendations for further exploration in areas not addressed within this investigation.

CHAPTER 2

LITERATURE REVIEW

Concrete is a material that has been widely used in construction due to its versatility and durability (Makul, 2020). Its popularity stems from a combination of factors such as its strength, affordability, and adaptability to various construction needs (Menna et al., 2020). Concrete is composed of a mixture of cement, water, and aggregates (such as sand and gravel), which undergoes a chemical reaction to form a solidified mass with high compressive strength. Over the years, the material has evolved with the use of additives and new technologies that have further enhanced its properties. These advancements have made concrete even more comprehensive and reliable in different applications (Makul, 2020).

One of the significant challenges in concrete technology is its susceptibility to tensile forces, which can cause cracking and ultimately result in failure. To address this problem, researchers have come up with various methods such as fiber reinforcement to enhance the tensile strength of concrete (Mailyan et al., 2021). As a result, fiber-reinforced concrete emerges as a modified version of traditional concrete, characterized by enhanced tensile strength, improved overall strength, reduced crack formation, increased toughness, and better durability (Wang et al., 2021).

2.1 Fibers in concrete

Fiber reinforcement involves the addition of either macro or micro fibers in concrete, which helps to distribute the tensile forces more evenly and minimize the risk of cracking and failure (Anas et al., 2022). This method offers a cost-efficient alternative to conventional reinforcement materials, significantly improving the properties of concrete. Widely recognized for its effectiveness, fiber reinforcement has gained popularity in contemporary construction practices, boosting concrete's durability and resilience. Consequently, this approach has improved concrete's utility across various applications, affirming its reliability and performance enhancement in the construction sector.

Concrete reinforcement is characterized by three predominant orientation strategies:

i. Three-Dimensional Random Distribution: This technique involves the use of either micro- or macro-fibers, which are uniformly mixed within the concrete, orienting in all directions. This method promotes a random fiber orientation, though it is estimated by (Kruschwitz et al., 2022) that merely about 15% of fibers are ideally positioned to effectively counter applied forces.
ii. Two-Dimensional Random Distribution: Characterized by methods such as the spray-up technique for fiber-reinforced concrete, this strategy orients fibers randomly but mainly within a singular plane. (Kruschwitz et al., 2022) notes that between 30% and 50% of fibers achieve an optimal orientation with this approach. Although more efficient than its three-dimensional counterpart, it typically does not provide sufficient reinforcement in the critical tension zones of concrete elements due to its primary horizontal plane orientation. This category also includes examples like thin cast plates and steel mesh reinforcement.
iii. One-Dimensional Reinforcement: The most traditional and efficient form of reinforcement uses steel bars, strategically placed in the tension zones of concrete structures to maximize reinforcement efficiency, as detailed by (Kruschwitz et al., 2022). This method ensures most of the reinforcing material is situated where it is most needed to enhance structural integrity.

2.1.1 Macro fibers

When macro fibers are added to concrete, their length ranges from 20 mm to 64 mm, with diameters spanning 0.5 mm to 2 mm. These fibers possess a tensile strength that varies between 120 MPa and more than 3000 MPa, alongside a modulus of elasticity ranging from 5 GPa to 200 GPa (Ahmad and Zhou, 2022). The introduction of macro fibers to fresh concrete slightly modifies its workability, albeit to a lesser extent compared to the addition of microfibers. The integration of macro fibers significantly improves the structural qualities of the concrete once it has hardened, providing advantages such as enhanced resistance to impact, increased strength under tension, improved ductility, and superior crack resistance following the formation of initial cracks.

2.1.2 Microfibers

Beyond fiber reinforcement, the incorporation of microfibers further augments the concrete's tensile properties, post-cracking behavior, and bond strength, contributing to its enhanced toughness and resilience. Microfiber dimensions span from 5 mm to 30 mm in length with diameters under 0.1 mm. Due to their slender shape, there is a limit to how much can be mixed in. Exceeding this limit with microfibers significantly impacts the ease of handling the fresh concrete. Typically, a proportion of 0.1% of microfibers by the concrete's volume is incorporated into the mix (Mizani et al., 2022).

Microfibers can be crafted from materials like polypropylene, nylon, or polyester, thus, minimize crack formation and bolstering the flexural strength of concrete. Additionally, the inclusion of microfibers in concrete delivers extra advantages such as improved fireproofing, reduced water penetration, enhanced shatterproof qualities and minimized plastic shrinkage cracking.

On the flip side, chemical admixtures are also mixed into the concrete during reinforcement to enhance its workability, adjust its setting time, and boost its durability. These admixtures can also fortify the bond between concrete and its reinforcing agents, thus amplifying the structural integrity. The application of microfibers and chemical admixtures is increasingly recognized in contemporary construction efforts for their pivotal role in elevating concrete's performance, making it more adaptable to a variety of stress conditions (Zhang et al., 2020).

2.1.3 Classification of fibers based on their origin.

There are two main types of fibers used in concrete, namely, synthetic and natural fibers. Natural fibers include materials such as coconut, abaca, kenaf, bamboo, sisal, chicken feather and jute, while synthetic fibers include steel, polymers, and glass. Each type of fiber has unique properties and can offer specific benefits to the performance of concrete.

Table 2.1 lists fibers belonging to various categories. The dimensions and forms of these fibers vary which plays a significant role in determining their bonding efficacy with the concrete mix. The table provides several mechanical properties that are valuable for selecting the appropriate fiber for use.

Table 2.1. Fibers Belonging to Various Categories (ACI Committee 544, 1996)

Fiber type	Tensile strength (MPa)	Elastic Modulus (GPa)	Specific gravity
Acrylic	296-1000	14-19	1.16-1.18
Alkali-resistant	2448-2482	79-80	2.7-2.74
Aramid I	2930	62	1.44
Aramid II	2344	117	1.44
Bagasse	184-290	15-19	1.2-1.3
Carbon I	1724	380	1.9
Carbon II	2620	230	1.9
Coconut	120-200	19-26	1.12-1.15
Glass	2000-4000	80	2.6
Nylon	965	5	1.14
Polyester	228-1103	17	1.34-1.39
Polyethylene	76-586	5-117	0.92-0.96
Polypropylene	138-690	3-5	0.9091
Sisal	276-568	13-26	-
Steel	1000-3000	200	7.8
Non Alkali-resistant	3103-3447	65-72	2.46-2.54

2.1.3.1 Synthetic fibers

Synthetic fibers play a crucial role in enhancing concrete performance. For example, steel fibers contribute essential tensile strength and ductility to concrete, addressing cracking issues and improving structural integrity. Polymers, such as polypropylene and polyester, act as crack-arresting elements, enhancing durability, while glass fibers provide flexibility and corrosion resistance, making them suitable for precast concrete and architectural features (Zheng et al., 2018).

Construction materials made of synthetic fibers offer a range of benefits. However, they also have certain limitations that need to be carefully considered. Therefore, it is crucial to choose construction materials thoughtfully to ensure their optimal performance and longevity. Effective material selection in construction projects requires a balanced assessment of both the advantages and disadvantages of synthetic fibers. Integrating synthetic and natural fibers in concrete provides a range of benefits (Ali et al., 2021), offering versatility and improved performance. This dual approach supports the development of eco-friendly construction practices, fostering a more sustainable approach to infrastructure development.

2.1.3.2 Natural fibers

Natural fibers are gaining recognition for their eco-friendly nature. These fibers offer mechanical characteristics surpassing conventional materials, inhibiting crack initiation, enhancing impermeability, and improving durability. However, precautions are necessary to be taken to address water absorption in plant-based fibers (Al-Maharma and Al-Huniti, 2019). Natural fibers (Figure 2.1) are promising for housing construction, inhibiting crack initiation and propagation while enhancing energy absorption capacity and ductility (Iniya and Nirmalkumar, 2021).

Figure 2.1: The natural fiber in cementitious composites (de Azevedo et al., 2021)

The potential of natural fibers in enhancing the mechanical properties of concrete has been increasingly recognized. Fibers such as coconut, bamboo, chicken feathers, and straw offer eco-friendly alternatives with unique attributes (Mochane et al., 2019). Notably, chicken feathers, a by-product of the poultry industry, are highlighted for their high tensile strength, making them a promising option for sustainable construction. Similarly, bamboo has emerged as a viable reinforcement material that can bolster the mechanical properties and durability of concrete, potentially serving as an alternative to traditional steel bars.

Specific studies, including those by (Jamshaid et al., 2022) on basalt fibers, (Bui et al., 2020) on coconut fibers, and (Wang et al., 2022) on pine needle fibers, demonstrate the substantial benefits these natural fibers can provide. This research emphasizes the broader application of natural fibers in reinforcing concrete, suggesting significant improvements in tensile strength, flexural strength, and toughness ratio. Furthermore, the cellulose content within these fibers is a key determinant of their mechanical properties, offering a pathway to more sustainable and effective construction materials (Bui et al., 2020).

In addition to these materials, studies have focused on the impact of fiber characteristics, such as length and volume, on material properties and resistance to cracking. For example, the work on basalt fiber underscores the critical role these factors play in determining the performance of composite materials (Wang et al., 2019).

The use of natural fibers in concrete reinforcement has garnered attention for their eco-friendly properties and ability to reduce environmental degradation and resource consumption (Jamshaid et al., 2022). Natural fibers enhance concrete's mechanical performance and interfacial bonding, providing post-cracking resistance and reducing energy consumption (Wang et al., 2022). Challenges such as scalability and brittleness are being addressed through innovations like new fiber treatments and hybrid fiber systems (Atmakuri et al., 2020). Natural fibers like jute, sisal, coir, and bamboo offer unique properties that enhance flexural capacity and freeze-thaw resistance. Ongoing research explores the feasibility and potential of natural fibers in construction, emphasizing sustainability, cost-effectiveness, and improved properties like abrasion resistance and thermal insulation (Lilargem Rocha et al., 2022).

Concrete hydration is the chemical reaction between cement and water, producing calcium silicate hydrate (C-S-H) gel, which provides strength and durability. While limited studies exist on chicken feathers in concrete, research on other natural fibers and lightweight aggregates indicates that untreated fibers or aggregates can absorb water, potentially affecting hydration and workability. For example, Ejigu and Gebre (2023) reported that the addition of sisal fibers decreased workability due to the absorption of a significant portion of water required for cement hydration by the hydrophilic fibers.

Similarly, Vijayalakshmi et al. (2023) noted that coconut shell aggregates absorb water, aiding the hydration process but potentially reducing workability if proper curing and water management are not applied.

2.2 Chicken Feathers as Natural Fiber

Chicken feather fibers, rich in keratin, have been identified as a sustainable alternative for reinforcing composite materials, thereby reducing reliance on synthetic polymers (Shavandi and Ali, 2019). Chicken feathers display a range of values for tensile strength, typically falling within 10 - >70 MPa, elastic modulus ranging from 3 - >50 GPa, and specific gravity spanning 0.7 - 1.2. These diverse properties render them promising for potential applications in composite building materials (Koniki and Prasad, 2019).

With an annual generation exceeding 4.8 million tonnes, exploring chicken feathers as natural fibers becomes crucial for sustainable and eco-friendly solutions. Their abundance positions them as an attractive alternative to synthetic fibers, addressing waste management and providing a renewable resource for diverse industries.

Pyrolyzing chicken feathers is an effective method for composite preparation, enhancing tensile and storage modulus in polymer composites (Verma et al., 2019). Chicken feather fibers possess a small diameter, making them suitable for applications in nonwoven insulation and air filtration. In addition, chicken feathers possess unique properties such as hollow honeycomb structures, low density, high flexibility, and potential structural interaction with other fibers, making them distinct from other natural or synthetic fibers (Paşayev et al., 2017). These properties are crucial for understanding the potential applications of chicken feathers in materials science.

2.2.1 Chemical Composition of Chicken Feathers

Table 2.2 provides a detailed summary of the chemical composition of chicken feathers, as reported by Tesfaye et al. (2018). The analysis revealed key components including keratin, proteins, and various trace elements. The feathers used in this study were carefully selected and characterized, with lengths ranging from 3 to 4.5 cm. This characterization is crucial for understanding the material properties and potential applications of chicken feathers, especially in the context of developing innovative composites and sustainable materials. The comprehensive chemical profiling conducted by Tesfaye et al. (2018) forms a foundational reference for further research and development in utilizing chicken feather fibers in industrial applications

Table 2.2 Chemical Composition of Chicken Feathers (Tesfaye et al., 2018)

Analysis	**Composition (%)**
Proximate Analysis	
Crude Lipid	0.83
Crude Fiber	2.15
Crude Protein	82.36
Ash	1.49
Nitrogen-Free Extract (NFE)	1.02
Moisture Content	12.33
Ultimate Analysis	
Carbon	64.47
Nitrogen	10.41
Oxygen	22.34
Sulfur	2.64

2.2.2 Previous research on the use of chicken feathers in concrete

Chicken feather waste has gained significant attention for its potential to enhance the properties of cementitious composites. Researchers have been increasingly exploring the use of chicken feather waste, and numerous studies have shown promising results in improving the mechanical strength, durability, and thermal insulation of these composites. Table 2.3 provides a summary of findings from selected studies that have incorporated chicken feathers as a natural fiber. These studies highlight the versatility and benefits of chicken feather fibers in various cementitious applications, demonstrating how this waste material can be effectively repurposed to improve construction materials. This growing body of research underscores the potential of chicken feather waste to contribute to more sustainable and high-performance building materials.

Table 2.3 Summary of selected few research which incorporated chicken feather as natural fiber.

S/N	**Author and Year**	**Major Findings**
1	Paşayev et al., 2017	- Chicken feathers possess unique properties like low density and hollow centers, making them suitable for reinforcement materials in composites.
2	Aranberri et al., 2019	-Found decreased elastic modulus and modulus of rupture with increased feather content, but whole chicken feathers improved flexural, tensile, and acoustic properties, outperforming processed feathers. - Highlighted improvements in the physical, mechanical, and thermal properties of polymer composites with chemically treated chicken feather fibers, suggesting sustainable applications.
3	Ouakarrouch et al., 2020	-Demonstrated thermal insulation properties in bio-composite materials using chicken feather ash as a partial cement replacement. - Cement-based composite materials reinforced with chicken feather fibers showed similarity in stiffness and strength to those reinforced with wood fibers.
4	Abdelsamie et al., 2021	-Adding chicken feathers in different proportions improved the tensile strength of concrete.
5	Pavithra et al., 2021	-Observed improved behavior of concrete with chicken feathers as fiber and partial replacement of cement with cashewnut shell powder.
6	Sutarno et al., 2021	-Explored the impact of feather fibers on thermal stability, potential for tailoring thermal properties, despite challenges like poor dispersion and hydrophobic nature of feathers. - Research on incorporating chicken feathers in concrete showed increased compressive strength with feather fiber addition. Characteristics of chicken feathers, such as difficulty in bonding with concrete and water absorption, can influence the compressive and flexural strengths of concrete.
7	Marinković et al., 2021	-Modification of chicken feather fiber/jute composites enhanced impact strength, with functionalized jute fibers improving flexural strength and modulus.
8	Mrajji et al., 2022	-Demonstrated improved impact strength in feather fiber-reinforced composites, suggesting applications in impact-resistant scenarios.

S/N	**Author and Year**	**Major Findings**
9	Oyebisi et al., 2022	-Replacing 8% of cement with cashew nutshell ash containing 1% chicken feather fiber resulted in higher compressive, splitting, and flexural strengths.
10	Kusumawardani et al., 2023	-Investigated keratin extraction from waste chicken feathers, and research explored concrete behavior with chicken feathers and cashew nutshell powder. - The studies collectively highlight chicken feathers' potential in construction materials, emphasizing their role in enhancing mechanical properties, sustainability, and reducing thermal conductivity.

2.3.3 Challenges of incorporating chicken feathers in concrete.

Incorporating chicken feathers in concrete poses several challenges that need to be addressed. However, the characteristics of chicken feathers, such as difficulty in bonding with concrete and high-water absorption, can lead to prolonged drying times for the concrete (Sutarno et al., 2021).

Chicken feathers are known to be strong in compression but weak in tension, which necessitates strategies to increase the tensile strength of concrete when using them as a reinforcement material (Abdelsamie et al., 2021). Moreover, the presence of fat in chicken feathers may hinder the adequate degradation of ß-keratin, potentially lowering the economic potential of utilizing chicken feathers in concrete (Barcus et al., 2017). Additionally, the unique properties of chicken feathers, such as low density and hollow centers, make them suitable for reinforcement in lightweight composites, but challenges remain in ensuring effective bonding with other materials (Njoku et al., 2019).

Utilizing chicken feather waste in construction materials is environmentally attractive due to the large poultry industry waste volume (Zahra et al., 2022). However, the fabrication process for incorporating chicken feathers in biodegradable matrices can pose practical challenges due to high temperatures (Dinu et al., 2020). Despite potential benefits as a reinforcement material in concrete, challenges like bonding issues, water absorption, fat content, and fabrication processes must be addressed for effective utilization of this sustainable resource. Yet, employing chicken feathers as a sustainable reinforcement in concrete and composites offers opportunities for enhancing material properties and reducing environmental impact.

The monitoring duration for chicken feather fiber concrete specimens for feather deterioration and effective mitigation strategies is a critical aspect that requires attention. While specific information on the exact duration for monitoring is lacking, it is essential to consider the long-term durability performance of such concrete structures. Studies have shown that the short-term mechanical properties of materials like carbon fiber concrete are well documented, but there is a need for further investigations into the long-term durability issues (Pacheco-Torgal et al., 2012).

Monitoring the deterioration mechanisms of concrete over time is crucial for predicting service life and diagnosing causes of deterioration, such as chloride ingress, carbonation, and sulphate attack (Yue et al., 2017). Additionally, the application of optical fiber Raman spectroscopy has shown potential for monitoring concrete subjected to sulphate attack, indicating a promising method for tracking deterioration processes (Yue et al., 2013).

To effectively mitigate the environmental consequences of chicken feather waste, urgent management strategies are required (Oluba et al., 2021). Utilizing chicken feather fibers in concrete mixtures can have varying effects on the properties of the concrete. For instance, a study found that a concrete mix containing 20% cashew nutshell ash and 2% chicken feather fiber resulted in an 8% increase in compressive strength compared to control concrete after 28 days of curing (Oyebisi et al., 2022). However, it is crucial to note that a high chicken feather content, such as 10%, is not recommended as it can significantly deteriorate various properties of the concrete (Taghiyari et al., 2021).

2.2.4 Preparation of chicken feathers for concrete application.

Chicken feathers, valued for their versatility, require meticulous cleaning to eliminate stains, fat, and odors, ensuring safety and quality (Paşayev et al., 2022). Studies by (Tesfaye et al., 2018) propose efficient cleaning methods involving sodium hypochlorite, non-ionic detergent, and sodium hydroxide. This combination effectively removes odor-causing substances without causing damage. (Mrajji et al., 2022) conducted comparative analyses of various cleaning methods, highlighting the importance of finding alternatives that balance efficacy, safety, and environmental considerations. This suggestion takes a unique approach by incorporating sunlight dishwashing liquid into the cleaning process to contribute to sustainable and practical cleaning solutions for chicken feathers.

Tesfaye et al. (2018) and El-Khordagui et al. (2021) both showed that a two-step regimen—detergent-based cleaning followed by disinfection—reduces microbial contamination on chicken feathers more effectively than cleaning alone. Using protease to assist the process, each study also reported efficient feather disintegration, a benefit for downstream applications such as insulation-grade feather fibres, laundry processing, and sustainable waste management. El-Khordagui et al. (2021) highlighted the use of protease enzymes for disintegrating chicken feathers, essential for applications in laundry and waste management. Proteases break down proteins present in feathers, facilitating their breakdown and removal during washing processes. This approach offers an alternative to traditional chemical-based cleaning methods, potentially reducing environmental impact and improving sustainability. Moreover, Tesfaye et al. (2018) discussed the challenges associated with completely removing environmental contaminants from feathers. Feathers can accumulate various pollutants, including heavy metals and organic compounds, posing risks to both human health and the environment. Efficient cleaning methods are necessary to mitigate these risks and ensure the safe disposal or reuse of feather-based materials.

Kelle and Eboatu, 2018 compared the effectiveness of chicken feathers and synthetic sorbents in cleaning up oil spills, demonstrating practical applications of feather-based materials in environmental remediation efforts. Properly cleaned feathers can serve as efficient sorbents for capturing and removing oil and other pollutants from contaminated environments, offering a sustainable solution to pollution mitigation challenges (Kelle and Eboatu, 2018).

These findings underscore the multifaceted importance of efficient and sustainable cleaning methods for chicken feathers, addressing a broad spectrum of industrial and environmental needs. These needs range from contamination reduction and waste management to the removal of environmental pollutants and overall pollution mitigation. Developing and implementing such methods are essential for promoting environmental sustainability and ensuring the responsible management of feather-based resources. This approach not only enhances the utility of chicken feathers in various applications but also contributes significantly to reducing the environmental impact associated with feather waste.

2.3 Coating Natural Fibers with Epoxy for use in Concrete

The use of epoxy coatings on natural fibers in concrete has demonstrated notable improvements in mechanical properties and durability. These coatings enhance degradation resistance and overall performance, especially when combined with nano-reinforcements (Owen et al., 2022). Epoxy coatings have a well-established role in protecting concrete substrates, providing high chemical and mechanical resistance while enhancing coating adhesion (Krzywiński et al., 2022). Their application extends to reinforcement bars, where epoxy-coated bars show enhanced bond strength, particularly in underwater concrete (Nie et al., 2020). Epoxy coatings also play a crucial role in structural health monitoring, aiding in detecting freezing-thawing and crack damage in concrete structures (Sánchez et al., 2018).

Coating techniques have been explored to address challenges like steel fiber corrosion, with studies indicating significant improvements through coating (Jalal et al., 2021). Innovative coating techniques, including fiber-reinforced polymer coatings and chemically reactive enamel-coated steel bars, contribute to enhancing the performance of fiber-reinforced concrete. Polymer coatings have been effective in retrofitting damaged concrete beams without compromising durability (Kocak et al., 2022). Chemically reactive coatings positively impact the system response of concrete structures, showcasing the potential of these coatings in improving concrete element behavior (Yan et al., 2016).

The strategic combination of epoxy coatings, natural and synthetic fibers, and innovative coating techniques holds great promise for elevating the mechanical properties, durability, and overall performance of concrete in diverse applications.

2.3.1 Previous studies on epoxy-coated natural fibers in concrete.

Several studies have investigated the use of epoxy coatings on natural fibers in concrete. (Owen et al., 2023) examined the effects of high-temperature optimization and resin coating treatment on the mechanical, thermal, and morphological properties of natural kenaf fiber-filled engineering plastic composites. The study involved coating kenaf natural fibers with acetone-thinned epoxy resin before compounding with high-temperature polyethylene terephthalate (PET) (Owen et al., 2023).

Owen et al. (2022) highlighted the capability of epoxy-coating of natural fibers to improve the degradation/decomposition resistance of the fibers, indicating a positive outcome of the epoxy coating on the fibers. Furthermore, Mahmood et al. (2016) evaluated the role of graphene nanoplatelets in epoxy matrix composite, either by sonication in the epoxy matrix or dip coating the fibers in graphene dispersion, suggesting the potential for enhancing interfacial adhesion in composites through coating treatments .

Hu et al. (2018) investigated the enhanced flexural performance of epoxy polymer concrete with short natural fibers, emphasizing the use of natural fibers to improve the mechanical properties of epoxy polymer concrete. Moreover, Hu et al., (2018) presented results on the electrochemical behavior of carbon fiber-reinforced polymer (CFRP) composite rods in contact with steel or epoxy-coated steel bars in chloride-contaminated concrete, indicating the potential protective role of epoxy coatings in concrete structures. These studies collectively demonstrate the potential benefits of epoxy coatings on natural fibers in concrete, including improved mechanical properties, enhanced degradation resistance, and protective effects on concrete structures. The findings suggest that epoxy coatings can positively impact the performance and durability of natural fiber-reinforced concrete (Hu et al., 2018).

2.4 Mix Design Considerations for Fiber-reinforced concrete

Optimizing the mix design for fiber-reinforced concrete is pivotal for achieving the desired mechanical and durability properties in various applications. Multiple factors must be carefully considered, including the type and volume fraction of fibers, their aspect ratio, mixing methods, and the influence of different fiber types on concrete properties (Guerini et al., 2018).

The mix design should address the specific characteristics of each fiber type, such as steel, polypropylene, basalt, and carbon fibers, as they can impact workability, strength, and durability. Hybridization of fibers, like combining steel and polypropylene fibers, necessitates optimization to achieve the desired mechanical properties (Dvorkin et al., 2021).

Furthermore, the mixing method, especially vibratory mixing, has been proven effective in enhancing the distribution of steel fibers, leading to increased density and improved mechanical properties (Zheng et al., 2018). Mechanical properties, including compressive strength, flexural strength, and shear capacity, should be a focus in mix design, along with considerations for environmental factors like freeze-thaw cycles and the use of materials such as fly ash to improve freeze-thaw resistance (Torres and Lantsoght, 2019).

Natural fiber-reinforced concrete offers a sustainable alternative, but the selection of natural fibers is crucial for optimal mix design. Different natural fibers, such as kenaf, bamboo, coconut, and palm frond fibers, impart distinct mechanical properties to concrete (Mouthanna, 2022). Understanding the specific influence of natural fiber types on concrete properties is essential for harnessing the full potential of natural fiber-reinforced concrete (Zhang and Pan, 2021).

To assess the impact of natural fiber-reinforced concrete on workability, slump test, and water absorption, various factors must be considered. Fiber addition can reduce workability and compressive strength, with higher fiber content leading to decreased mobility of the concrete (Okeola et al., 2018). Water absorption in natural fiber-reinforced concrete is influenced by fiber type, as seen in studies combining nylon and jute fibers or using steel fibers in recycled concrete aggregate mixes (Bheel et al., 2021).

The slump test, a measure of workability, is affected by the addition of fibers, with higher content reducing slump (Zhang and Pan, 2021). However, dispersed reinforcement, including fibers, can enhance concrete characteristics related to workability and cracking resistance (Deaconu and Chiţonu, 2022).

Overall, optimizing fiber-reinforced concrete and natural fiber-reinforced concrete mix designs requires a comprehensive approach considering fiber types, volume fractions, aspect ratios, mixing methods, and environmental factors. Understanding the specific influences of each factor is crucial for achieving the desired mechanical and durability properties in fiber-reinforced concrete.

2.5 Testing and Optimization on Chicken Feather Fiber Concrete

2.5.1 Compressive strength test conducted on chicken feather fiber concrete.

The compressive strength test of concrete serves as a fundamental measure of its performance and durability (Kurnianingsih et al., 2023). Research into incorporating chicken feather fiber into concrete has yielded varying effects on compressive strength. (Sutarno et al., 2021) observed that adding 1% chicken feather fiber increased compressive strength, while a 2% addition resulted in a decrease. Similarly, (Rumbayan et al., 2019) noted a 19% improvement with a 0.25% fiber inclusion. These findings underscore the significant role of fiber proportion in determining compressive strength. Moreover, the compressive strength of chicken feather fiber concrete is influenced not only by the percentage of fiber but also by its specific characteristics. Understanding these effects is vital for developing sustainable and high-performance construction materials.

Investigations into varying percentages of chicken feathers in concrete mixtures have revealed direct impacts on compressive strength. (Kurien et al., 2022) demonstrated that chicken feather fiber can enhance mechanical properties, potentially boosting compressive strength. Additionally, although not focusing on chicken feathers directly, (Young et al., 2019) provided insights into the relationship between mixture proportions and compressive strength, which are relevant for considering the influence of chicken feathers in concrete mixtures.

2.5.2 Splitting tensile strength test conducted on chicken feather fiber concrete.

The splitting tensile strength test is commonly utilized to assess concrete's tensile strength (Słowik and Akram, 2021). Studies on fiber-reinforced concrete have explored various aspects, including the impact of fiber volume fractions and types on splitting tensile strength (Zhang et al., 2023). In the specific case of chicken feather fiber concrete, investigations have shown an increase in compressive strength with the addition of chicken feather fiber (Sutarno et al., 2021). Additionally, research on fiber-reinforced polyester using chicken feather fiber demonstrated the potential for enhancing tensile strength in composites (Loganathan et al., 2020).

Despite extensive research on the mechanical properties of fiber-reinforced concrete, there remains a gap regarding the physical structure and tensile properties of chicken feather barbs. However, studies on lightweight concrete reinforced with polypropylene fibers have indicated an increase in splitting tensile strength (Guo et al., 2019). Furthermore, investigations into polylactide/poly (methyl acrylate) grafted chicken feather composites have shown improved tensile strength and modulus after modification (Chen et al., 2020). Determining the optimal proportion of chicken feathers in concrete for achieving maximum tensile strength has been a subject of interest. (Sutarno et al., 2021) found that a 1% addition of chicken feather fiber significantly increased compressive strength compared to no addition, aligning with (Verma et al., 2019) forecast for hybrid composites. However, Sutarno et al. (2021) cautioned against exceeding 5 wt% of feathers, noting a significant decline in mechanical properties beyond this threshold. This underscores the importance of balancing feather content to enhance compressive strength without compromising mechanical properties (Sutarno et al., 2021).

2.5.3 Flexural strength test conducted on chicken feather fiber concrete.

Flexural strength tests conducted on chicken feather fiber concrete have shown promising results in enhancing the mechanical properties of the concrete. Artayani et al. (2024) found that the addition of chicken feather fibers improved the flexural strength of Portland cement concrete, particularly with a dosage lower than 2%. Additionally, Rao et al. (2021) demonstrated that a combination of chicken feather fiber and kenaf fiber resulted in a maximum flexural strength of 24.89 MPa. These studies highlight the potential of chicken feather fibers in enhancing the flexural strength of concrete composites. Moreover, research by Reddy & Yang (2010) showcased the positive impact of chicken feather fiber composites on properties such as tensile strength, modulus, and flexural strength. The composites exhibited good mechanical properties when treated with Zinc Oxide and when reinforced with whole chicken feathers, indicating the versatility and strength-enhancing capabilities of chicken feather fibers. The incorporation of chicken feather fibers in concrete has shown to be a viable method for improving flexural strength. By leveraging the reinforcing properties of these fibers, concrete composites can achieve enhanced mechanical performance, making them a promising sustainable solution in construction materials.

2.5.4 Other Durability Tests

The current literature on chicken feather fiber reinforced concrete is notably deficient in comprehensive studies addressing critical tests such as the Oxygen Permeability Index (OPI), Sorptivity, Chloride Conductivity, and Dry Shrinkage. Despite the potential advantages of using chicken feather fibers in concrete, there is a glaring absence of detailed research and data on these essential parameters. These tests are paramount for evaluating the durability, permeability, moisture absorption, and overall long-term performance of chicken feather fiber reinforced concrete in construction applications. The lack of such information in the existing body of work significantly hampers the understanding and optimization of this innovative composite material, underscoring an urgent need for focused studies to fill these critical gaps.

2.5.3.1 Oxygen Permeability Index (OPI) Test

The OPI test evaluates oxygen ingress into concrete, crucial for assessing durability in corrosive environments. Understanding the impact of chicken feather fibers on OPI will fill a significant gap in research, providing insights into material longevity and oxidative resistance.

2.5.3.2 Sorptivity Test

Sorptivity measures moisture absorption, essential for evaluating concrete's resistance to deterioration. Investigating sorptivity in chicken feather fiber concrete will inform mix design improvements and enhance material performance in various environmental conditions.

2.5.3.3 Chloride Conductivity Test

Assessing chloride ion permeability is vital for concrete durability, particularly in marine and de-icing salt environments. Examining how chicken feather fibers affect chloride conductivity will guide strategies to mitigate corrosion and enhance material resilience.

2.5.3.4 Dry Shrinkage Test

Dry shrinkage affects concrete's structural integrity and crack susceptibility. Researching dry shrinkage in chicken feather fiber concrete will aid in developing crack-resistant designs and ensuring long-term structural stability.

2.6 The incorporation of plasticizer in chicken feather fiber concrete

The incorporation of plasticizer in chicken feather fiber concrete can offer several advantages in terms of enhancing the properties of the concrete. Plasticizers are additives commonly used in concrete to improve workability, reduce water content, and increase the strength of the final product. When incorporating chicken feather fibers into concrete, the addition of a plasticizer can aid in dispersing the fibers evenly throughout the mixture, leading to improved mechanical properties such as compressive strength and flexural strength (Sutarno et al., 2021).

CHRYSO®Fluid Premia 310 is an advanced superplasticizer widely recognized for its ability to enhance the properties of concrete. Formulated with a modified polycarboxylate polymer, it is tailored for applications requiring high short and long-term strength, facilitating the achievement of very low water/cement ratios. This product is particularly noted for its effectiveness in improving concrete workability and strength, making it suitable for various construction needs.

2.7 Current trends in percentage utilization of chicken feather waste fibers as concrete reinforcement

In their study, Sutarno et al. (2021) explored the potential of utilizing chicken feather waste fibers as a natural fiber reinforcement in concrete mixtures to enhance its characteristics. They focused on improving the strength properties of concrete, which typically exhibits strength against compressive forces but is weaker in resisting tensile forces. The research involved the addition of chicken feather waste fibers, with a length of 3 cm, to concrete mixtures with a grade of 20 MPa. Three different percentages of chicken feather waste fibers (0%, 1%, and 2% of the volume of concrete) were incorporated into the mix. Compressive strength and flexural strength tests were conducted on concrete specimens, using cylindrical specimens measuring 15 x 30 cm for compressive strength and beam specimens measuring 15 x 15 x 60 cm for flexural strength. Each percentage of chicken feather waste fibers was tested with five samples (Sutarno et al., 2021).

The results indicated that the addition of 1% chicken feather waste fibers led to an increase in compressive strength compared to both the 0% and 2% addition rates. Specifically, the compressive strength values were 200.78 kg/cm² for 0% addition, 215.09 kg/cm² for 1% addition, and 197.54 kg/cm² for 2% addition. However, the flexural strength values showed a decreasing trend with increasing percentages of chicken feather waste fibers, with values of 24.00 kg/cm², 23.03 kg/cm², and 21.08 kg/cm² for 0%, 1%, and 2% addition rates, respectively. The study concluded that while the addition of chicken feather waste fibers improved compressive strength at the 1% addition rate, higher percentages led to decreased compressive strength. Additionally, the flexural strength of the concrete was not significantly affected by the addition of chicken feather waste fibers. This was attributed to the difficulty of bonding between the chicken feathers and the concrete, as well as the fibers' tendency to absorb water, prolonging the drying time of the concrete after maintenance (Sutarno et al., 2021).

2.8 Gaps in the Literature Review

To address the identified gaps in the current research on the use of chicken feathers in concrete, the following issues have been outlined along with corresponding recommendations. This will provide a clear path for future research and practical applications.

2.8.1 Limited Long-Term Durability Insights

Comprehensive and long-term investigations into the use of chicken feathers in concrete are crucial for gaining extended insights into their performance. While existing studies have primarily focused on the short-term effects of incorporating chicken feathers into concrete mixes, there is a need to delve deeper into the long-term implications.

To address this gap, comprehensive, long-term durability investigations must be conducted to tackle concrete shortcomings in permeability and durability. These studies are essential to thoroughly understand how chicken feather fiber reinforced concrete) performs under various environmental conditions over extended periods. Only through rigorous and detailed testing can the true potential of chicken feather fiber reinforced concrete be realized, ensuring its viability as a durable, sustainable construction material. This will not only fill the current void in the literature but also pave the way for innovative applications in the construction industry.

2.8.2 Underexplored Processing Methods Impact

The existing literature lacks coverage on how different processing methods of chicken feathers affect concrete performance. This gap in research means that the influence of various cleaning, treatment, and preparation techniques on the mechanical and durability properties of chicken feather fiber reinforced concrete remains largely unexplored. Understanding the impact of these processing methods is crucial for optimizing the use of chicken feathers in concrete, as different treatments could significantly alter the fibers' effectiveness in enhancing concrete properties. Addressing this gap is essential for advancing the application of chicken feather fibers in sustainable construction materials.

2.8.3 Neglected Influence of Feather Size and Structure

Minimal research exists on how the size and structure of chicken feathers affect concrete properties. This lack of detailed studies means that the potential variations in mechanical strength, durability, and other key characteristics of chicken feather fiber reinforced concrete based on feather dimensions and morphology are not well understood. The size and structure of the feathers could play a significant role in the performance of the composite material, influencing factors such as fiber distribution, bonding with the cement matrix, and overall structural integrity. Addressing this research gap is essential for optimizing the use of chicken feathers in concrete and fully harnessing their potential benefits in construction applications.

2.8.4 Lack of Standardization and Guidelines

The absence of standardized guidelines for incorporating chicken feathers in concrete significantly hinders widespread adoption of this innovative material. Without clear and universally accepted protocols, engineers, researchers, and manufacturers face challenges in consistently producing and evaluating chicken feather fiber reinforced concrete chicken feather fiber reinforced concrete across different applications and contexts. Standardized guidelines are crucial for ensuring quality control, optimizing material performance, and promoting confidence among stakeholders regarding the durability, sustainability, and safety of chicken feather fiber reinforced concrete. Addressing this issue requires collaborative efforts among researchers, industry stakeholders, and regulatory bodies to develop comprehensive guidelines that cover aspects such as feather processing, mix design, testing protocols, and performance criteria. Establishing these guidelines will not only facilitate broader acceptance and adoption of chicken feather fiber reinforced concrete but also encourage its integration into mainstream construction practices.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter details the experimental procedures carried out during the research, including testing methods, visual documentation, technical evaluations, and procedural sequencing. The focus was on assessing various properties of concrete through a series of tests, including workability, compressive strength, splitting tensile strength, dry shrinkage, durability, and morphology. The experimental procedure was divided into two distinct phases to comprehensively assess the properties of both fresh and hardened concrete. In the first phase, the emphasis was on the properties of fresh concrete. Workability, a key property reflecting how easily the concrete can be mixed, placed, and finished, was evaluated using the slump test. This test measures the consistency of the concrete and its suitability for various applications.

In the second phase, the focus shifted to evaluating the hardened concrete properties. This phase included tests to assess workability, with methods such as the slump test used for this purpose. Additionally, properties such as compressive strength, which measures the concrete’s ability to withstand axial loads, and splitting tensile strength, which evaluates the resistance of concrete to tensile stresses, were examined. Other critical properties assessed included permeability, which measures the concrete’s ability to allow fluids to pass through, and sorptivity, which gauges the rate of moisture absorption. Chloride conductivity, which affects the concrete's durability by indicating its ability to conduct chloride ions, and morphology, which analyzes the shape and texture of the concrete particles, were also studied. Dry shrinkage, the dimensional changes of the concrete as it dries, was evaluated to understand its stability. This comprehensive analysis provided a thorough understanding of the concrete’s behavior under different loading conditions, its durability against moisture and chloride ingress, and its dimensional stability with respect to dry shrinkage.

3.2 Material

The investigation involved a blend of materials, encompassing cement, untreated chicken feathers, water, epoxy-coated chicken feathers, coarse aggregates, and fine aggregates. The integration of superior-grade cement, appropriate aggregates, and purified water established a robust foundation for conducting thorough assessments and analyses of the fresh and hardened characteristics of the concrete reinforced with chicken feathers.

3.2.1 Ordinary Portland cement (OPC)

To ensure the quality and consistency of the concrete specimens, meticulous attention was given to the selection and utilization of materials during the casting process. The study exclusively used Ordinary Portland cement (OPC) CEM I 52.5N, adhering to South African Standards SANS 50197-1. Ordinary Portland Cement (CEM I 52.5N), supplied by PPC Cement SA (Pty) Ltd, was chosen for this study. While blended cements are more commonly used in South African construction today, OPC is particularly appropriate for research. Its use without extenders allows for a clearer understanding of the effects of adding alternative materials. Plate 3.1 depicts a sample of the cement that was measured and utilized during the mixing phase. This research aimed for an expected target strength of 52.5 MPa at 28 days for the concrete specimens. This target strength was determined based on the measured strength of the cement, aligning with common concrete requirements. Additionally, Table 3.1 depicts the chemical composition of the utilized cement.

Plate 3.1: Weighing of cement utilized in the concrete mixing process.

Table 3.1 Chemical composition of the OPC used.

Chemical Properties	Result (%)	Specification: SANS 50197-1
Lime (CaO)	63.12	None
Silica (SiO_2)	20.81	None
Alumina (Al_2O_3)	4.83	None
Iron Oxide (Fe_2O_3)	2.18	None
Sulphuric anhydride (SO_3)	2.17	≤ 3.5 %
Magnesia (MgO)	2.24	None *
Potassium Oxide (K_2O)	0.17	None
Sodium Oxide (Na_2O)	0.23	None
Chloride content	0.0	≤ 0.10 %
Product Composition		
Clinker	96.13	90
Limestone (NDM)	3.87	≤ 5
Comments: * Specification requirement for Clinker: MgO max. 5.0 %. SANS 50196-2		

3.2.2 Coarse aggregates

In choosing the coarse aggregates, a size of 22.4 mm was specifically chosen, and these aggregates were procured from the Afrisam Jukskei plant, Johannesburg South Africa. These coarse aggregates play a pivotal role in providing bulk and stability to the concrete mixture, ultimately contributing to its overall strength and load-bearing capacity. The meticulous selection of aggregates is crucial to achieving the desired properties and optimal performance of the final concrete product. Aggregate selection is a critical aspect, as aggregates typically make up 60-75% of the total volume in a concrete mix, significantly influencing the characteristics of the concrete. Plate 3.2 shows the weighing of the coarse aggregates utilized in the concrete mixing process.

Plate 3.2: Weighing of the coarse aggregates utilized in the concrete mixing process.

3.2.3 Fine aggregates (Unwashed Sand)

Fine aggregates were sourced from unwashed crusher sand, a common material in construction projects, crucial for imparting workability and cohesion to the concrete mix.

Plate 3.3 depicts the weighing of the crusher sand used in the concrete mixture. The treatment process for the crusher sand mirrored that of the coarse aggregates, following AfriSam standards, and ensuring compliance with SANS 201:2008 and SANS 5838:2006 before its final incorporation. The fine aggregates were subjected to the sieve analysis process. The fine aggregates underwent sieving using progressively finer mesh sizes, with the quantity of material retained on each sieve being quantified and represented as a percentage. This examination aids in assessing the particle size distribution and grading of the fine aggregates, factors pivotal in influencing the workability and strength of the concrete mixture. AfriSam conducted reference checks in accordance with both SANS 201:2008 and SANS 5838:2006.

Plate 3.3:Weighing f the crusher sand used in the concrete mixture.

Sieve analysis was intended to determine the particle size distribution and fineness modulus (FM) of fine aggregates. A set of sieves, ranging from 37.5 mm to 0.075 mm, was used for the sieve analysis. The fine aggregate sample was first evenly distributed using a riffler, dried to a constant mass, and weighed. To remove dust and clay lumps, the sample was washed, and the water was decanted through sieves. After washing, the sample was dried again. The dried sample was passed through the sieves, and the mass retained on each sieve was weighed. The fineness modulus was calculated by summing the cumulative percentages retained on specific sieves and dividing by 100. Safety precautions, such as wearing gloves and safety glasses, were followed throughout the experiment. This process provided insights into the fine aggregate's suitability for concrete applications.

3.2.4 Water

Water, a crucial component in concrete mixture, was sourced directly from the University of South Africa Civil Engineering laboratory. It was imperative to use clean water meeting the standards outlined in SANS 2001-1:2007/EN 1008. The quality of water used in concrete casting significantly impacts setting time, workability, and overall strength development. The water used in this research was tap water, free from salt or any soluble substances. Before utilization, it was maintained at either cool or room temperature. The source of the water was directly from the University of South Africa Civil Engineering laboratory.

3.2.5 Chicken Feathers

The chicken feathers used in this study were responsibly sourced from Rand Vaal Chickens farm, situated in the Vaal region, in the southern part of Gauteng province, South Africa, adhering to sustainable and ethical practices. To prepare the feathers for incorporation into the concrete mixture, a series of thorough steps were followed.

3.2.5.1 Feather Preparation for Experimental Use

The feathers were carefully separated from any unwanted elements, such as chicken heads, feet, and intestines, to ensure that only clean and appropriate feathers were utilized in the experiment. This process helped maintain the integrity and quality of the feathers, allowing them to serve their intended purpose effectively.

3.2.5.2 Cleaning Process for Chicken Feathers

The feathers underwent a thorough cleaning process. They were washed in a mild soapy water solution, ensuring the removal of any dirt, debris, or contaminants that might have been present. This cleaning step was essential to enhance the cleanliness and hygiene of the feathers, as well as to eliminate any potential factors that could adversely affect the concrete mixture.

3.2.5.3 Optimal Air-Drying of Cleaned Chicken Feathers

The feathers were carefully air-dried after the cleaning process, allowing them to regain their natural moisture content and texture. Plate 3.4 Shows the Air-Drying process of cleaned chicken feathers. Proper drying is crucial to ensure that the feathers are in an optimal state for incorporation into the concrete mix. The feathers intended for use as untreated specimens were set aside after drying, ready for subsequent testing and analysis.

Plate 3.4: Air-Drying of cleaned chicken feathers

3.2.6 Epoxy Resin

The treated feathers underwent an additional process involving coating with Clear Epoxy Resin, aiming to reinforce them and enhance compatibility with the concrete matrix. Plate 3.6 shows the Clear Epoxy Resin that was used to coat the chicken feathers. This innovative resin, derived from 37% plant-based materials, reduces reliance on fossil fuels, aligning with environmental sustainability goals. Certified by independent laboratories using Carbon 14 measurements, it offers transparency and accountability. Clearcast

Epoxy Resin provides enhanced ultraviolet resistance, safeguarding finished products against sunlight damage and ensuring prolonged durability, crucial for outdoor applications. Its versatility extends to various uses such as casting decorative objects, crafting jewelry, or producing industrial prototypes like river tables.

3.2.6.1 Coating of the dried chicken feathers

The clear epoxy resin was mixed using a 2:1 ratio, as follows. The workspace was prepared with proper ventilation, and safety measures were observed by wearing gloves and safety glasses. The necessary materials were gathered, including the clear epoxy resin components (resin and hardener), measuring tools, mixing containers, and stirring implements. Components were measured accurately: 200 ml of resin was combined with 100 ml of hardener to achieve a total of 300 ml of mixture. The resin was poured into a clean, dry mixing container, followed by the addition of the hardener. The mixture was stirred gently but thoroughly with a clean stir stick, ensuring a uniform blend by scraping the sides and bottom of the container. Mixing continued for 2-3 minutes, or as specified by the manufacturer, to ensure no streaks or unmixed areas remained. Air bubbles were minimized by stirring slowly, and any that formed were allowed to settle naturally. After mixing, the resin was used to coat chicken feathers. Each feather was placed individually into a mould. The well-mixed resin was poured over the feathers in the mould, and the setup was left to dry for 4 days. Following this drying period, the feathers were demoulded, leading to a successful outcome of coated chicken feathers. Plate 3.5 depicts the coated chicken feathers.

Plate 3.5 :Coated chicken feathers

Plate 3.6: Clear Epoxy Resin

3.2.7 Plasticizers

In this study, CHRYSO®Fluid Premia 310 was selected as the superplasticizer of choice. Plate 3.7 shows the plasticizer that was used in this study. The dosage guidelines recommended ranged from 0.3 to 3.0 kg per 100 kg of cement, with a typical dosage of 1% of the cement weight. It was added to the mixing water to ensure homogeneous distribution within the concrete mixture. Storage conditions were maintained above 0°C to prevent freezing, adhering to its shelf life of 12 months.

3.2.7.1 Application of Plasticizer in Untreated Chicken Feathers Mixture

The initial mixture of untreated chicken feathers was found to be excessively dry, requiring adjustment to achieve the desired consistency. To address this, a plasticizer was introduced to enhance the workability of the mixture. The plasticizer was first combined with the mixing water to ensure even distribution throughout the mix. Specifically, 20 ml of plasticizer was added to the water. This prepared solution was then thoroughly incorporated into the concrete mix, aiming to improve the overall texture and performance of the final product.

Plate 3.7 :The plasticizer that was used in this study: CHRYSO®Fluid Premia 310

3.2.8 Equipment used in this study.

The mixing process involved using a concrete mixer, which ensured thorough and uniform blending of the concrete ingredients. For smaller batches, hand tools like mixing paddles were employed for manual mixing. Accurate measurement of materials was crucial; therefore, weighing scales were used to measure the precise weight of cement, aggregates, and other components. Measuring cylinders and jugs were utilized to ensure the correct volume of water and admixtures. Once the ingredients were mixed, the concrete was placed into various moulds, including cylindrical, cubic, and prismatic shapes, which were prepared with mould release agents to prevent sticking.

To achieve proper compaction and eliminate air bubbles, a vibrating table was used. Additionally, tamping rods were employed for manual compaction, especially in smaller Moulds. After casting, the concrete specimens were cured to attain the desired properties. This process involved using a curing tank for water immersion and a humidity chamber to maintain a controlled environment. Testing the concrete's strength and other characteristics required specific equipment as prescribed in the relevant standards. A compression testing machine was used to determine the compressive strength of the specimens, while a flexural testing machine assessed their flexural strength. The tensile strength was measured using a split tensile testing machine. Non-destructive testing methods were also incorporated to evaluate the concrete's hardness and internal integrity.

A rebound hammer was used for hardness testing, and an ultrasonic pulse velocity tester provided insights into the internal condition of the concrete. Miscellaneous tools, such as buckets and pails, shovels and trowels, brushes, and sponges, were necessary for handling, mixing, and cleaning processes. Throughout the methodology, personal protective equipment (PPE), including gloves, safety goggles, and lab coats, was used to ensure safety during the concrete mixing and handling procedures. This comprehensive list of equipment and their applications underscores the meticulous approach taken in the preparation and testing of concrete specimens, ensuring that each step was conducted with precision and care.

3.3 Preparation of Material

To establish an effective testing methodology, five scenarios were developed, incorporating different percentages of chicken feathers by mass of the concrete: Mix 1- 0% CF, Mix 2- 1% UCF, Mix 3- 1% TCF, Mix 4- 0.75% TCF, and Mix 5- 1.25% TCF. This selection was informed by previous research, notably by (Sutarno et al., 2021), which identified 1% as the optimal percentage. Table 3.2 shows the comprehensive description of the mixes.

The first mix, Mix 1- 0% CF, served as the baseline without any chicken feathers incorporated. It represented the standard concrete mixture used for comparison purposes. Mix 2- 1% UCF, labelled as 1% untreated, contained 1% of untreated chicken feathers by mass. These feathers were incorporated into the mix without any additional treatment or coating. Mix 3- 1% TCF, labelled as 1% treated, also contained 1% of chicken feathers by mass. However, in this mix, the feathers underwent a treatment process where they were coated with a clear epoxy resin to enhance their properties and compatibility with the concrete matrix. Mix 4- 0.75% TCF, labelled as 0.75% treated, had a reduced percentage of chicken feathers compared to the previous mixes. Specifically, it contained 0.75% of treated feathers by mass. Mix 5- 1.25% TCF, labelled as 1.25% treated, had a higher percentage of treated chicken feathers, amounting to 1.25% by mass.

Table 3.2 Mixes comprehensive description

Mix ID (Chicken Feathers Content by percentage (%))
Mix 1- 0% CF
Mix 2- 1% UCF
Mix 3- 1% TCF
Mix 4- 0.75% TCF
Mix 5- 1.25% TCF

3.4 Mix design

The concrete mix design adhered to the specifications outlined in the SANS 10100:2000 standard. However, a critical consideration was the water-to-cement ratio, which required careful attention. Initial observations revealed that when incorporating chicken feathers, the original mix design yielded a dry mixture. Plate 3.8 depicts dry concrete mixture in cube mould with incorporated chicken feathers. Due to the dryness, there was no bonding between the stones and the feathers during compaction. This dryness stemmed from the high-water absorption capacity of the feathers, impeding adequate moisture availability for the hydration process. Recognizing this challenge, adjustments to the water-to-cement ratio became imperative to ensure proper workability. These modifications aimed to provide sufficient moisture to the mix, facilitating the hydration process effectively. Moreover, the unique properties of chicken feathers as reinforcement material necessitated alterations in both water content and stone content to achieve an optimal and workable concrete mix.

Plate 3.8: Dry concrete mixture in cube mould with incorporated chicken feathers.

The adaptation of the mix design underscored the importance of considering the distinctive characteristics of chicken feathers in concrete formulation. By addressing these challenges through precise adjustments, the research aimed to optimize the concrete's composition while ensuring the successful integration of chicken feathers as reinforcement material. This meticulous process of mix design adjustment not only aimed to maintain desired workability but also sought to enhance overall performance. Ultimately, the research aimed to establish a concrete mixture where chicken feathers could be seamlessly incorporated, thereby enhancing the structural properties of the material.

The concrete mixing adhered to the specifications outlines in the SANS 5863:2006 for hardened concrete. The concrete mixing with untreated chicken feathers specifically underwent an adjustment in the water-to-cement ratio. Initial observations indicated that the incorporation of untreated chicken feathers led to a dry mixture due to their high-water absorption capacity. This adjustment aimed to address the insufficient moisture available for the hydration process. By modifying the water-to-cement ratio, the objective was to ensure proper workability while accommodating the unique characteristics of untreated chicken feathers as reinforcement material.

In addition, it's worth noting that CHRYSO®Fluid Premia 310 was exclusively utilized for the mix containing untreated chicken feathers.

3.5 Testing Timetable

Table 3.3 presents the total count of specimens prepared for this investigation, alongside the testing techniques and mould dimensions utilized. The experimental work was conducted with careful attention to material selection and precise testing procedures. All tests were performed in accordance with established standards to ensure accurate and reliable results. The thorough evaluation of the effect of mix design on chicken feathered concrete was made possible through these meticulous testing procedures.

Table 3.3: Presents the total count of specimens prepared for this investigation

Test Name	**Test Standard**	**Number of Samples**	**Total Specimens**	**Age of the Sample**	**Sample Size**
Workability (Slump)	SANS 5862-1:2006	5	10	After mixing	slump test cone
Compressive strength	SANS 5863:2006	15 cubes/mix	75	7, 14, 28, 56 and 90	100 mm cube
Splint Tensile strength	SANS 6253:2006	15 cubes/mix	75	7, 14, 28, 56 and 90	100 mm cube
Dry Shrinkage	SANS 3001-CO2-7	3 beams/mix	15	7, 14, 28, 56 and 90	100x100x300 mm beam
Oxygen permeability, sorptivity and chloride conductivity	SANS 3001-CO3-2, SANS 3001-CO3-1, SANS 3001-CO3-3	12 cubes/mix	60	28, 56, and 90	100 mm cube to produce 68 x 30 mm discs
100x100x100mm cubes = 210 specimens 100x100x300mm beams = 15 specimens					

3.6 Testing Methodology

Concrete mixing was performed using a concrete mixer according to SANS 5861-1. First, the specified proportions of cement, aggregates, and water were carefully measured according to the mix design requirements. The aggregates were then introduced into the mixer followed by the cement. The mixer was started, and water was added gradually while monitoring the consistency of the mixture. Mixing continued until a uniform and homogeneous concrete mix was achieved, with all ingredients thoroughly combined. The mixing time for the concrete was kept constant to ensure uniform distribution of the chicken feather fibers in the mix. The following testing procedures were being carried out for both fresh and hardened concrete specimens.

3.6.1 Slump Test

The slump test was being conducted on fresh concrete specimens to determine the workability of the mix. The test was being performed according to SANS 5861-2:2006.

The slump test was conducted to assess the workability and consistency of the freshly mixed concrete. A slump cone with a base diameter of 200mm, top diameter of 100mm, and height of 300mm was placed on a smooth, flat surface. The cone was filled with freshly mixed concrete in three layers, each layer being compacted using a tamping rod. After filling, the cone was carefully lifted vertically, and the settlement of the concrete was measured from the top of the cone to the displaced center of the concrete mass. The average of three measurements was recorded as the slump value.

3.6.2 Casting of Concrete Cubes

Concrete cubes measuring 100mm x 100mm x 100mm were cast to assess the compressive strength of the concrete. The cube moulds were thoroughly cleaned and oiled to prevent sticking. The freshly mixed concrete was then poured into the moulds in three layers, each layer being compacted using a tamping rod to ensure proper compaction and removal of air voids. After filling, the surface of the concrete was levelled using a trowel, and the moulds were covered with a damp cloth to prevent moisture loss during curing. The cubes were labelled with identification details and left undisturbed for 24 hours before demoulding. After demoulding, the cubes were cured in water at a temperature of 20 ± 2°C until the testing age.

After casting, the concrete specimens were allowed to cure in a controlled environment with a stable temperature and humidity for a specified period, typically 24 hours. This initial curing helped in achieving proper hydration and strength development of the concrete. Following the initial curing period, the specimens were removed from the moulds and further cured under standard curing conditions, typically in a curing chamber or water tank, to ensure uniform curing throughout the specimens. During the casting process, vibrating tables operated mechanically were utilized to ensure proper compaction of the concrete specimens. These tables were designed to securely hold the concrete moulds, allowing them to be clamped tightly. The vibration was applied for a duration of 10 minutes consistently across all the casting procedures to achieve full compaction of the concrete. This process ensured that the concrete mixture was evenly distributed and free of air voids, promoting the overall quality and strength of the specimens. This process was done according to SANS 5862-1: 2006 and SANS 5861-3: 2006.

After casting, the concrete specimens were subjected to a curing process following the guidelines outlined in SANS 5861-3:2006. To initiate the curing process, the specimens were immediately covered with an impervious sheet a few minutes after casting. This sheet provided a protective barrier, preventing the evaporation of moisture from the concrete and maintaining a favorable curing environment. For the initial 24 hours of curing, the specimens were stored on a concrete table within the laboratory under a controlled temperature of approximately +23°C. After this initial period, the specimens were carefully demoulded and transferred into a control-curing tank. Plate 3.9 shows the curing tank used in this study. The curing tank was maintained at a temperature of ±22°C, providing a consistent and controlled curing environment for the specimens. The use of impervious sheets during the early stages of curing and the subsequent transfer to a dedicated curing tank ensured that the concrete specimens received optimal moisture retention and temperature conditions for the duration of the curing process. This approach facilitated the development of proper hydration and strength gain in the concrete, contributing to the desired mechanical and durability properties of the specimens.

Plate 3.9: Curing Tank used in the curing process.

3.6.3 Water Absorption Test

The water absorption test was conducted to assess the porosity and moisture absorption characteristics of concrete cubes at different stages of curing. This test provided insight into the concrete's permeability and long-term durability. Concrete cubes were cast in moulds, allowed to set, and then transferred to a curing tank where they were fully submerged in water. On specific testing days—namely days 7, 14, 28, 56, and 90—a set of cubes was removed from the tank for water absorption testing. Each cube was first wiped with a clean cloth to remove surface water and then weighed to obtain the wet mass. The cubes were then placed in a ventilated oven set at 105 ± 5 °C for 24 hours, as required by the standard, to remove all internal moisture. After oven-drying, the cubes were allowed to cool in a desiccator before the dry mass was measured. The differences between the wet and dry masses were recorded for each cube. These values were used to evaluate how much water had been absorbed during the curing period. All results were logged in a spreadsheet and compared across the various curing intervals to assess the concrete's moisture absorption behaviour and durability performance.

3.6.4 Compressive strength test

The compressive strength test for concrete cubes was carried out using a series of standard procedures outlined in SANS 5861-3:2006. Concrete cubes measuring 100mm x 100mm x 100mm were created from fresh concrete. This process involved filling cube moulds with concrete and compacting the mixture to remove air pockets and ensure uniformity. The cubes were covered with plastic and then left to set for 24 hours in a controlled environment to maintain consistent moisture and ambient temperature. After 24 hours, the cubes were removed from the moulds and placed in a curing tank with a consistent water temperature of ± 22°C to maintain moisture. The cubes were then tested at specific time intervals: 7, 14, 28, 56, and 90 days.

The compressive strength test was conducted using a hydraulic press, as shown in Plate 3.10. The concrete cube was carefully positioned on a steel plate within the press to ensure proper alignment and full surface contact, which is essential for accurate load distribution. The hydraulic press applied a gradually increasing load to the cube, avoiding any sudden application of force. This controlled loading process continued steadily until the cube reached its failure point, where it could no longer withstand the applied pressure. This method ensured a consistent and gradual application of force, allowing for an accurate measurement of the concrete’s compressive strength, and prevented any abrupt breakage, which could skew the results. The maximum load applied to the cube was recorded. This load was divided by the cross-sectional area of the cube to determine the compressive strength, typically expressed in megapascals (MPa).

Plate 3.10 :Hydraulic press used for compressive strength testing.

Each test was repeated with a set of three cubes for each time interval to ensure accuracy and reliability of the results. Plate 3.11 displays the screen showing the compressive strength results. The average of the three compressive strength values was calculated for each interval. Results were documented, allowing for a comparison of compressive strength development over time. These tests were crucial for assessing the concrete's strength characteristics and ensuring it met the required standards for construction and engineering purposes The compressive strength testing adhered to the specification in SANS 5863: 2006.

Plate 3.11: Screen showing the compressive strength results.

3.6.5 Split tensile strength test

The split tensile strength test could be performed on hardened concrete specimens to evaluate the tensile strength of the mix. The test was being performed according to SANS 6253:2006. The testing procedure involved the following steps: Cubes were selected from the curing environment for testing at designated intervals 7, 14, 28, 56, and 90 days.

A tensile strength testing machine was prepared, ensuring it was calibrated and in proper working condition. The machine was configured to apply tensile force evenly across the concrete cubes. Each cube was positioned within the testing machine such that the applied tensile force would create a split along one of its faces. Special loading devices or plates were used to ensure even force distribution, reducing stress concentration and preventing premature failure. Plate 3.12 shows the splitting tensile strength set up. The machine applied a steadily increasing tensile load to the concrete cube until failure occurred, typically manifesting as a clean split across the cube's surface. The rate of loading was controlled to comply with the SANS 6253:2006 standard. The tensile strength at the point of failure was recorded for each cube. This data was used to determine the split tensile strength at each curing interval (7, 14, 28, 56, and 90 days).

Plate 3.12: Fastened Concrete cube on a Splitting-tensile steel-plates

After all tests were completed, the results were analyzed to assess the development of tensile strength over time. This analysis provided insights into the durability and long-term strength of the concrete, aiding in the evaluation of its performance and suitability for various construction applications.

3.6.6 Durability test

In recent years, researchers in South Africa have developed unique durability index tests tailored to the country's needs. These tests include the Oxygen Permeability Index, Chloride Conductivity Index, and Water Sorptivity Index, providing comparative measures of concrete's resistance to chloride and/or carbon dioxide penetration. Table 3.5 outlines suggested ranges for classifying concrete durability based on these tests currently utilized in South Africa.

Table 3.4: The acceptance criteria for durability index testing (Alexander et al., 2001).

Durability Class	**OPI (Log scale)**	**Sorptivity (mm/√h)**	**Cl Conductivity (mS/cm)**
Excellent	>10	<6	<0,75
Good	9,5 - 10	6 - 10	0,75 – 1,50
Poor	9,0 – 9,5	10 - 15	1,5 – 2,50
Very Poor	< 9,0	>15	>2,50

This study conducted three durability index tests at a Concrete Testing laboratory in South Africa, where specimens were prepared following the specifications outlined in SANS 3001-CO3-1:2015.

3.6.6.1 Preparation of specimens

Once the concrete had cured, the specimens were marked to indicate where the cores would be extracted. Using a core drill with a diamond-tipped bit, cylindrical cores were extracted from the concrete specimens. The core drill was equipped with a water-cooling system to reduce heat and prevent dust. Core diameters typically ranged from 68 ± 2 mm specimens. Care was taken to maintain the vertical alignment of the core drill to ensure that the cores were extracted straight. Plate 3.13 shows how the cylinders looked like after coring.

Plate 3 13: Cylindrical concrete cores after coring

In this study, concrete cubes were cored in a controlled laboratory setting to create slices of 25 ± 2 mm thickness. The cores were obtained directly from standardized concrete cube samples, not from in situ structures. Each cube was secured on a cutting machine equipped with a precision diamond blade, and the machine was calibrated to ensure the uniform thickness of the slices. This calibration included checking the blade alignment and adjusting the cutting speed. The cores were cut perpendicular to their longitudinal axis to create the required disc slices. Plate 3.14 shows the disc slices. The cutting process used water to cool the blade and reduce dust. The slices were carefully collected and marked for further testing. After cutting, the surfaces of the disc slices were cleaned and smoothed to remove any rough edges or irregularities caused by the cutting process. This preparation ensured that the slices were ready for durability testing.

Plate 3.14: The prepared disc slices

The prepared disc slices were then set up for specific durability tests, such as chloride conductivity, Oxygen Permeability Index, and Sorptivity test. The setup depended on the specific test being conducted. Durability tests were conducted according to standardized methods, with conditions such as temperature and humidity controlled to ensure consistent results. During testing, the specimens were exposed to the necessary environmental factors to evaluate their durability. Test results, such as penetration depth or permeability, were recorded for analysis. The test data was used to assess the durability and expected lifespan of the concrete under various conditions.

3.6.6.2 Oxygen permeability index

The Oxygen Permeability Index (OPI) testing procedure involves several systematic steps following a preconditioning period of one week at 50 ± 20°C in an oven. Initially, each specimen is positioned face down in a rubber collar within a permeability cell and covered with a plate. The regulator gas is then adjusted to maintain approximately 100 kPa pressure (± 5 kPa), with residual gases purged by allowing oxygen flow for five seconds through open inlet and outlet valves of each cell. Subsequently, the outlet valve is closed until the pressure gauge reaches over 100 kPa (± 5 kPa). Measurements are then taken at 15-minute intervals across four cells to ensure accuracy, continuing until the pressure drops to 50 kPa (± 5 kPa), typically taking about six hours (± 15 minutes). Plate 3.15

illustrates the apparatus used for the OPI testing, which provides essential data on specimen permeability.

The South African OPI test method, conforming to SANS 3001-CO3-2:2015, involves placing a 68 ± 2 mm diameter by 25 ± 2 mm thick concrete disc in a falling head permeameter. A pressure gradient is applied across the specimen, and pressure decay within the cell is monitored per SANS 3001-CO3-2:2015 specifications. This method is crucial for material evaluation, mix proportion design, research, development, and on-site concrete quality control. For each test, four specimens are required, each prepared according to precise dimensions and curing requirements. After oven curing for seven days, followed by cooling in desiccators at controlled temperature, specimens are swiftly transferred to the pressure vessel. Testing starts at 100 kPa ± 5 kPa and concludes when the pressure drops to 50 kPa ± 2.5 kPa or after six hours ± 15 minutes. Readings, taken at 5 kPa ± 1 kPa intervals, are crucially recorded for analysis, with automated data capture capabilities as depicted in Plates 3.15 and 3.16.

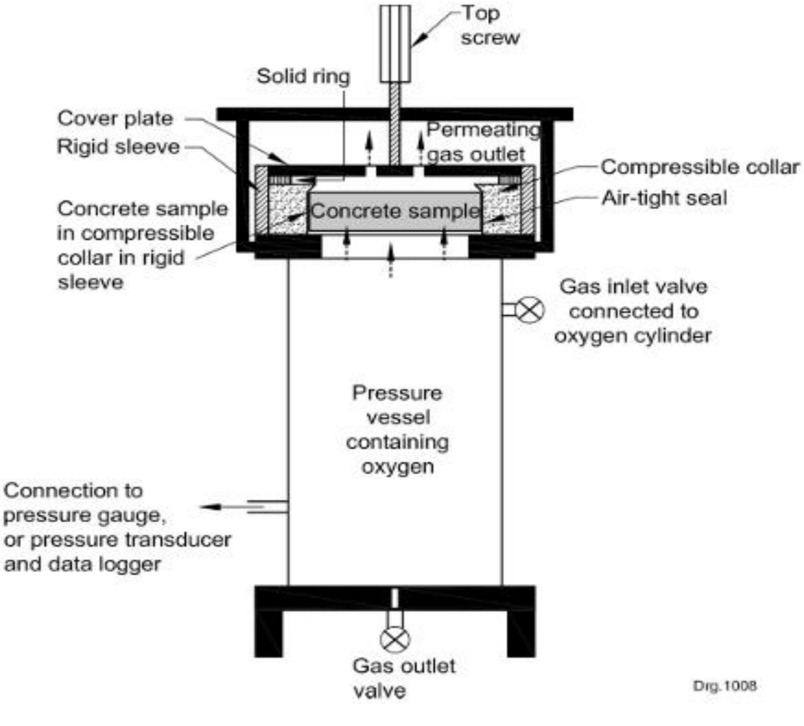


Plate 3.15: A schematic example of an OPI test apparatus (Durability Index Testing Procedure Manual, 2023.

Plate 3.16: Oxygen Permeability Index Apparatus

The coefficient of permeability is calculated for each of the test specimens. The OPI is given as the negative log of the average of the coefficients of permeability of the specimens, which for four specimens is:

$$OPI = -\log_{10}[[¼\,(k1 + k2 + k3 + k4)] \quad (3.1)$$

Where:

k = coefficient of permeability of test specimen (m/s) from the Darcy's coefficient of permeability which is given by:

$$k = \frac{\omega V g d z}{R A \phi} \quad (3.2)$$

OPI’s are logarithmic values and range generally from 8 to 11, that is three orders of magnitude; the higher the index, the less permeable the concrete.

3.6.6.3 Sorptivity test

The Water Sorptivity test measures the rate at which water penetrates a concrete surface, indicating its capillary suction properties and permeability. The process begins with conditioning concrete disc samples in a low humidity environment. Each specimen, following conditioning, is a 68 mm ± 2 mm diameter disc with a thickness of 25 mm ± 2 mm, prepared according to SANS 3001-CO3-1 standards. Initially, the specimens' dry masses are measured and recorded. The circular surfaces are sealed, typically with paint or masking tape, to ensure uni-directional water absorption during testing. The test apparatus consists of a steel tray lined with ten layers of absorbent paper soaked in a calcium hydroxide ($Ca(OH)_2$) solution, prepared at 5 grams per liter of water and maintained at 23°C (±2°C). The solution saturates the paper, leaving a thin visible layer on top. Excess water is gently pressed out to eliminate air bubbles, maintaining the water level no more than 2 mm above the specimen's sides.

At the start of the test (time 0), each specimen is weighed to the nearest 0.01 gram and placed on the wet absorbent paper. A stopwatch is initiated to record time intervals for subsequent weighings: 3, 5, 7, 9, 12, 16, 20, and 25 minutes. Careful handling ensures each weighing process does not exceed 15 seconds to minimize potential impacts on results. Following the initial sorptivity test phase, the specimens undergo vacuum saturation. They are placed in a tank under -75 kPa to -80 kPa pressure for approximately three hours, ensuring full saturation with the calcium hydroxide solution. After this vacuum period, the tank is filled with saturated solution, maintaining an air-free environment, and left for an additional hour. Subsequently, the specimens soak for 18 hours ± one hour to complete the saturation process. Upon removal from the solution, each specimen is patted dry to a Saturated Surface Dry (SSD) condition using absorbent paper and immediately reweighed with precision to monitor any mass changes. The sorptivity is determined through the plot of water absorbed versus the square root of time, derived from the mass data collected during the test intervals. This comprehensive process ensures accurate measurement of the specimens' water absorption characteristics, crucial for evaluating concrete's permeability and durability. Plate 3.17 shows the water sorptivity test apparatus.

The effective porosity (n) of each specimen is determined as follows:

$$n = \left[\frac{Msv - Ms0}{GAD\rho w}\right] x\ 100 \tag{3.3}$$

Where:

n = effective porosity

Msv = the vacuum saturated mass.

$Ms0$ = mass of the specimen at t = 0 to the nearest 0,01 g.

A = cross-sectional area of the specimen to the nearest 0,02 mm^2.

D = average specimen thickness to the nearest 0,02
mm. ρw = density of water = 10^{-3} g/mm^3.

The water sorptivity of the specimen (S) is given by;

$$S = \frac{Fd}{Msv - Ms0} \tag{3.4}$$

Where:

F = the slope of the best fit line (5 g), in grams per square root of the hour.

Other parameters are as previously described.

The lower the water sorptivity index, the better is the potential durability of the concrete.

Sorptivity values typically vary from approximately 5 mm/√h, for well-cured concrete, to 20 mm/√h for poorly cured concrete.

Plate 3.17 :Water sorptivity test apparatus

3.6.6.4 Chloride conductivity

The Chloride Conductivity test involves the measurement of a sample’s electric conductivity in accordance with SANS 3001-CO3-3:2015 method. Four test specimens are required per test. The test specimen shall consist of a 68 mm ± 2 mm diameter concrete disc with a thickness of 25 mm ± 2 mm cored and cut in accordance with Durability Index Testing Procedure Manual, 2023. The concrete specimens are dried in an oven and vacuum pre-saturated with a 5 M NaCl solution. The Chloride Conductivity testing process involves a saturation method with vacuum pressures of -75 kPa and -80 kPa. The Chloride Conductivity test is conducted in two phases as follows:

In the first phase, specimens are saturated in a vacuum tank for approximately 3 hours (±15 minutes). The tank is then isolated to allow a salt solution to enter, ensuring the specimens are submerged at least 40 mm without air ingress. The vacuum pump is reconnected to the chamber, maintaining the pressure for another hour (±15 minutes). Afterward, the vacuum is released, letting air into the specimens while they soak for an additional 18 hours (±1 hour). Once the soaking period is complete, each specimen is removed, dried with a paper towel until the surface is dry, and then weighed with an accuracy of 0.01 grams. The specimens are placed in the vacuum saturation tank that is evacuated to between -75 and -80 kPa and is maintained under vacuum of between -75 and -80 kPa for 3 hours ±15 min. After three hours ±15 min the tank is isolated and the salt solution is allowed to enter the vacuum tank without releasing the vacuum to cover all the specimens to a depth of approximately 40 mm. The vacuum is re-established between -75 kPa and -80kPa and maintained for one hour ± 15 minutes. After one hour ± 15 min, the vacuum is released, and air is allowed to enter. The specimens are then soaked for a further 18 hours ± one hour. After 18 hours ± one hour soaking, the specimens are removed from the solution and the surface is dried with a paper towel to a SSD condition and weighed. This is recorded as the vacuum saturated mass MS of the specimen. The test procedure commences immediately after this weighing.

The second phase focuses on the conductivity test itself. The connecting points of the Chloride Conductivity apparatus are unscrewed to fill the luggin capillaries with 5.0 M Sodium Chloride (NaCl). Specimens are placed in a flexible collar with one face against the lip of the rigid ring. The combined sections are then screwed into the anode part, ensuring that the solid plastic lip compresses the flexible collar.

Next, the conduction cell is positioned horizontally in the apparatus, connecting the ammeter and voltmeter. The power supply is adjusted until the voltage across the specimen is approximately 10 volts. The current and voltage readings are recorded, allowing for manual calculation of both the Chloride Conductivity and Sorptivity reports. This procedure should be completed within 15 minutes after the specimens are removed from the NaCl solutions to ensure accurate results. A conduction cell is used, in which the sample is placed between two cells containing 5 M NaCl solution as shown in Plate 3.18.

A potential difference is applied across the sample, causing a movement of chloride ions, and the corresponding current is used to calculate the concrete's conductivity, which in turn can be related to the concrete's resistance to chloride ingress. This procedure gives an instant reading.

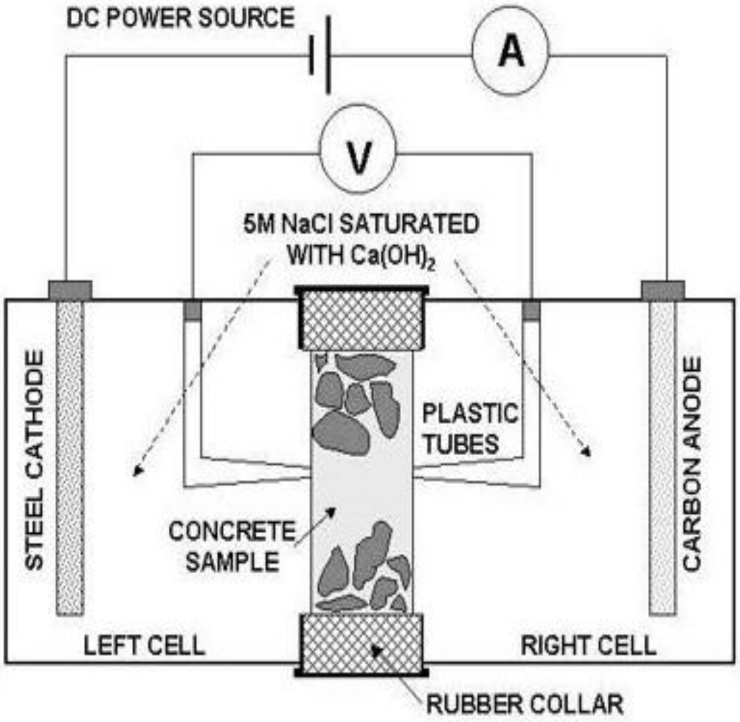


Plate 3.18: Schematic drawing of Chloride Conductivity test apparatus (The Concrete Portal, n.d.)

For each test specimen, the Chloride Conductivity is calculated individually using the equation;

$$\sigma = \frac{it}{VA} \tag{3.5}$$

Where:

σ = conductivity of the specimen (mS/cm).

i = electric current
(mA.) *V* = voltage
difference (V).
t = average thickness of specimen (cm).
A = cross-sectional area of the specimen
(cm²).

The porosity (n) of each specimen is determined as follows:

$$n = \left[\frac{Ms - Md}{\mathrm{AD\rho w}}\right] x\ 100 \tag{3.6}$$

Where:

n = effective porosity

Ms = the vacuum saturated mass of the specimen the nearest
0,01 g *Md* = mass of the dry specimen to the nearest 0,01g. *D*
= average specimen thickness to the nearest 0,02 mm.
ρw = density of salt solution = 1,19 x10^{-3} g/mm3.

3.6.7 Dry Shrinkage test

The drying shrinkage test was performed on hardened concrete specimens to determine the amount of shrinkage that occurred as the concrete dried. The test was being performed according to SANS 3001-CO2-7. A concrete mix was prepared according to the mix design. The mix typically consisted of cement, coarse aggregates, water, fine aggregates, untreated chicken feathers and treated chicken feathers. Plate 3.19 shows the concrete specimens measuring 100 mm x 100 mm x 300 mm that were cast from the prepared concrete mix. This was typically done using moulds to achieve the desired dimensions and shape.

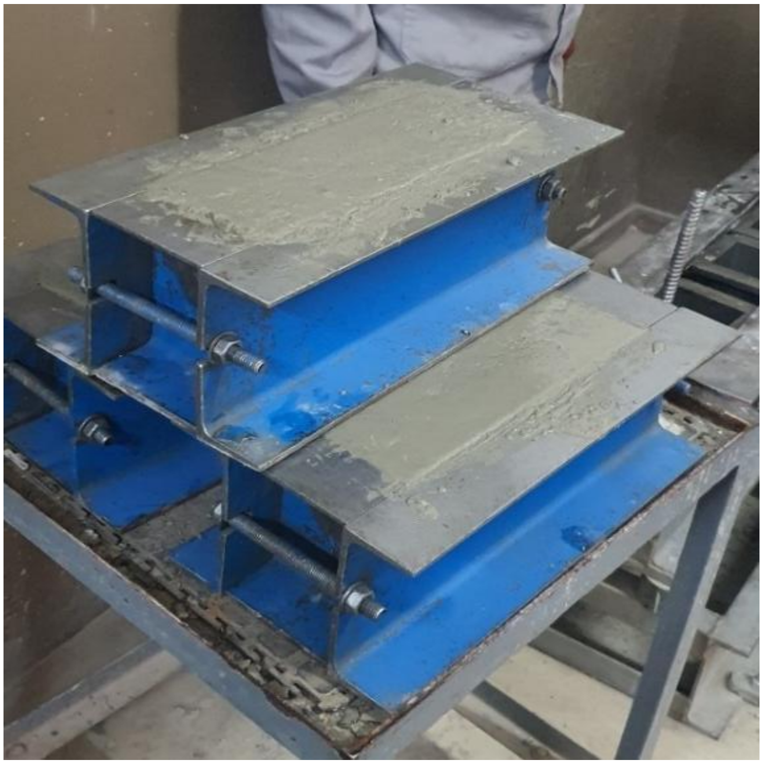


Plate 3.19: Concrete specimens measuring 100mm x 100mm x 300mm being cast from the prepared concrete mix for dry shrinkage test.

The concrete was compacted thoroughly in the moulds to ensure proper consolidation and elimination of any air voids. This was done using a vibrating table. Before starting the dry shrinkage test, the initial dimensions (length, width, and height) of each concrete specimen were measured accurately using callipers. These measurements served as the baseline for comparison during the test. The concrete specimens were placed in a controlled drying environment with low relative humidity (typically less than 50%) to simulate the absence of moisture. This drying phase induced shrinkage in the concrete specimens due to moisture loss. Throughout the drying phase, the dimensions of the concrete specimens were measured at regular weekly intervals using callipers. The measurements included the length, width, and height of each specimen. The measurements of the dimensions of the concrete specimens were recorded accurately at each interval. This data provided information on the extent of shrinkage experienced by the specimens over time during the drying phase.

The drying shrinkage and wetting expansion test procedure, based on SANS 3001-CO2-7, was carried out by first preparing specimens that were cured in water for 7 days ± 2 hours. After curing, the specimens were removed from the water, wiped dry, and the anvils were cleaned. The initial measurement (L1) was then taken using precise measuring equipment to the nearest 2 μm, ensuring that each specimen was consistently oriented in the same direction for all subsequent measurements. Thereafter, the specimens were placed in a drying chamber maintained at a temperature of 50 °C to 55 °C and a relative humidity of 15% to 25% for a period of 7 days. Once removed from the drying chamber, they were cooled to a temperature between 22 °C and 25 °C and re-measured in the same orientation. This drying and measuring cycle was repeated at 48-hour intervals until the change between two successive readings was less than or equal to 2 μm per 100 mm of the nominal specimen length. The lowest measurement recorded was noted as L2.

If wetting expansion was required, the dried specimens (after recording L2) were prepared by greasing the anvils and immersing the specimens in clean potable water at 22 °C to 25 °C for 3 days ± 2 hours. The specimens were then re-measured, and this process of immersion and measurement was repeated in 48-hour intervals until two successive readings differed by no more than 2 μm per 100 mm. The highest reading obtained was recorded as L3.

The drying shrinkage of each specimen was calculated using the formula (L1−L2)/L0×100(L1 - L2) / L0 \times 100(L1−L2)/L0×100, where L0 was the initial distance between the innermost faces of the anvils, measured to the nearest millimetre. Similarly, if wetting expansion was measured, it was calculated using the formula (L3−L2)/L0×100(L3 - L2) / L0 \times 100(L3−L2)/L0×100. All individual and average values for drying shrinkage and wetting expansion (if performed) were recorded to the nearest 0.001%. The range of values was also assessed, and if the variation among the three specimens exceeded 20% of the average, the results were considered suspect, and the test was repeated.

3.6.8 Statical analysis

The appropriate statistical test was selected based on the research objectives and data characteristics. For comparing test scores between two groups, a t-test was chosen. The t-test was executed in the Statistical Package for the Social Sciences by selecting the relevant variables and specifying the test type, ensuring that the assumptions required for the test, such as normality and homogeneity of variances, were met. The statistical test was run, and the p-value was obtained. The p-value indicated the probability of observing the data, or something more extreme, under the null hypothesis. A p-value less than 0.05 was considered statistically significant, suggesting that the observed difference was unlikely to have occurred by chance.

Results were interpreted based on the p-value. A p-value less than 0.05 suggested a statistically significant difference between the test scores of the two groups, supporting the alternative hypothesis and indicating that the new teaching method had a significant impact on student performance. Conversely, a p-value greater than 0.05 indicated no significant difference, supporting the null hypothesis and suggesting that the new method did not have a measurable impact compared to the traditional method. The findings were presented clearly and structured to highlight the p-value and discuss its significance in relation to the research objectives. This approach ensured a thorough analysis, focusing on the key statistical measure for drawing conclusions.

3.7 Safety and Quality Assurance

Throughout the testing process, safety measures were strictly adhered to, including the use of protective equipment and clear safety zones around the Universal Testing Machine. The calibration of the testing equipment was checked before each test to ensure accuracy. The study was non-human and did not involve any human or animal objects. Ethical clearance was sought and confirmed as not required by the Institutional Ethics Committee.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this chapter, the results and discussions of various tests conducted on concrete materials are presented. These tests include an analysis of aggregates, slump, density, compressive strength, split tensile strength, and durability, covering oxygen permeability, sorptivity, chloride conductivity, and dry shrinkage. The results of these tests are discussed in detail, providing insights into the performance of the materials, along with statistical analysis and observations.

4.1 Aggregates

4.1.1 Coarse Aggregate Densities

The density-related characteristics of the coarse aggregates were recorded as follows: Relative Density (RD) of 2.67, Loose Bulk Density (LBD) of 1370 kg/m³, and Consolidated Bulk Density (CBD) of 1420 kg/m³. These values reflect a well-graded aggregate with good compactability and the potential to contribute to concrete strength.

4.1.2 Grading of Coarse Aggregates

The grading results of the aggregates are presented in this section, with particular emphasis on their implications for mix design, as well as the overall quality and durability of the resulting concrete. The physical properties of the coarse aggregates used in this study were assessed to confirm their suitability for concrete production. These properties include grading and size distribution, as presented in Table 4.1.

Table 4.1: The coarse aggregates size distribution.

GRADING					
Sieve Size (mm)	**Mass Retained (g)**	**Individual % retained**	**Cumulative % Retained**	**% of material that passed**	**Specification % passing**
28.0	0	0	0	100.0	100
22.4	140	5.5	5.5	94.5	80-100
20.0	511.0	20.2	25.7	74.3	55-85
14.0	1766.0	69.8	95.5	4.5	0-25
10.0	103.0	4.1	99.6	0.4	0-7
0.075	2.0	0.1	99.7	0.3	0-2
PAN (c)	7.0	0.3	100		
Total	2530.0				

The grading analysis of the coarse aggregates demonstrated full compliance with the specified particle size distribution requirements The coarse aggregate grading curve, as shown in Figure 4.1, indicates that 100% of the sample passed through the 28.0 mm sieve, demonstrating full compliance with the specified grading requirements. The material retained on the 22.4 mm sieve was 5.5%, resulting in 94.5% passing, which is within the 80-100% specification range. For the 20.0 mm sieve, 74.3% of the material passed, fitting well within the 55-85% specification range. At the 14.0 mm sieve, 4.5% of the material passed, meeting the stringent 0-25% specification. The 10.0 mm sieve recorded 0.4% passing, adhering to the 0-7% specification. Finally, 0.3% of the material passed through the 0.075 mm sieve, within the acceptable 0-2% range.

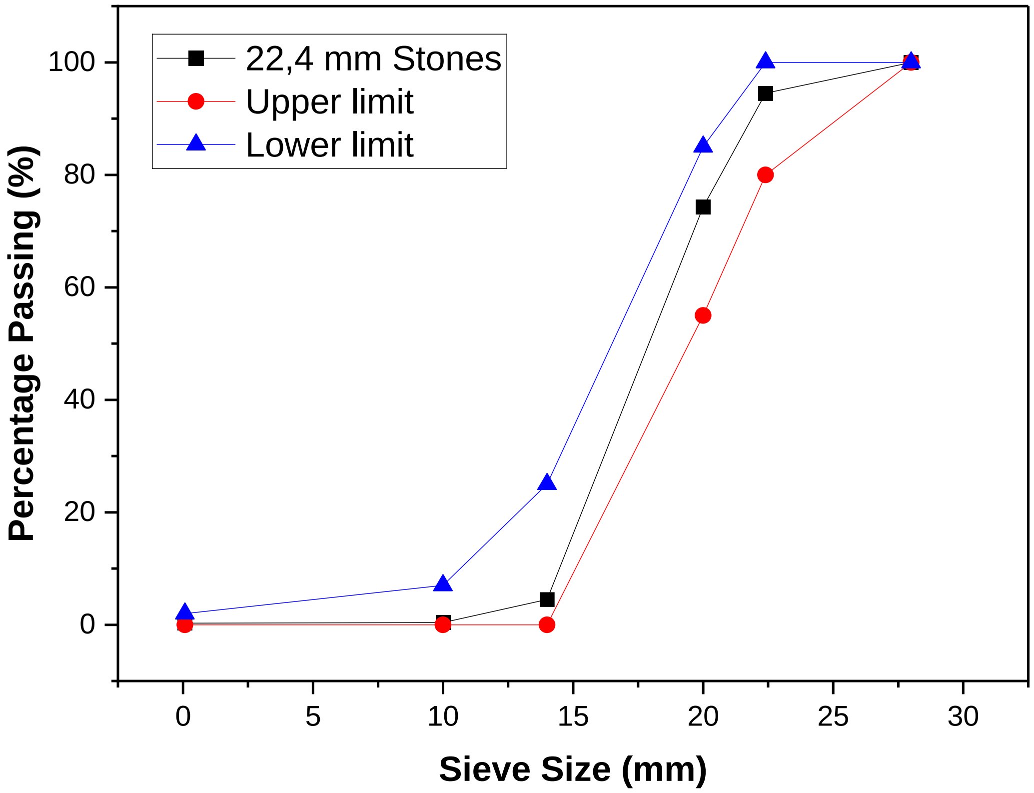


Figure 4.1: Coarse aggregate grading curve

The grading curve aligns well with the required specifications, indicating that the aggregates are well-graded and suitable for use in concrete mix applications, providing the desired properties for strength, durability, and workability**.**

4.1.3 Grading of Fine aggregates (Unwashed Sand)

The sieve analysis results for the fine aggregates are presented in Table 4.2, highlighting the distribution of particle sizes across various sieve sizes.

Table 4.2:The fine aggregates size distribution.

			GRADING		
Sieve Size (mm)	**Mass Retained (g)**	**Individual % retained**	**Cumulative % Retained**	**% of material that passed**	**Specification % passing**
7.1	0.0	0.0	0.0	100.0	99-100
5.0	36	6.5	6.5	93.5	92-98
2.00	158.0	28.6	35.1	64.9	54-74
1.00	96.0	17.4	52.4	47.6	34-54
0.600	77.0	13.9	66.4	33.6	23-43
0.300	67.0	12.1	78.5	21.5	14-30
0.150	52.0	9.4	87.9	12.1	8-20
0.075	30.0	5.4	93.3	6.7	6-14
PAN (c)	36.0	6.5	99.8		
TOTAL	553.0				

The grading table analysis indicated that the fine aggregate sample complied with the specified particle size distribution requirements. For the 7.1 mm sieve, 100% of the material passed, meeting the 99-100% specification range. The 5.0 mm sieve allowed 93.5% of the material to pass, within the 92-98% range. For the 2.00 mm sieve, 64.9% passing falls within the 54-74% specification. The subsequent sieves (1.00 mm, 0.600 mm, 0.300 mm, 0.150 mm, and 0.075 mm) showed passing percentages of 47.6%, 33.6%, 21.5%, 12.1%, and 6.7%, respectively, all within their specified ranges. The grading curve shown in Figure 4.2 demonstrates that the crusher sand exhibits consistent conformity across all sieve sizes. This indicates that the fine aggregate is well-graded

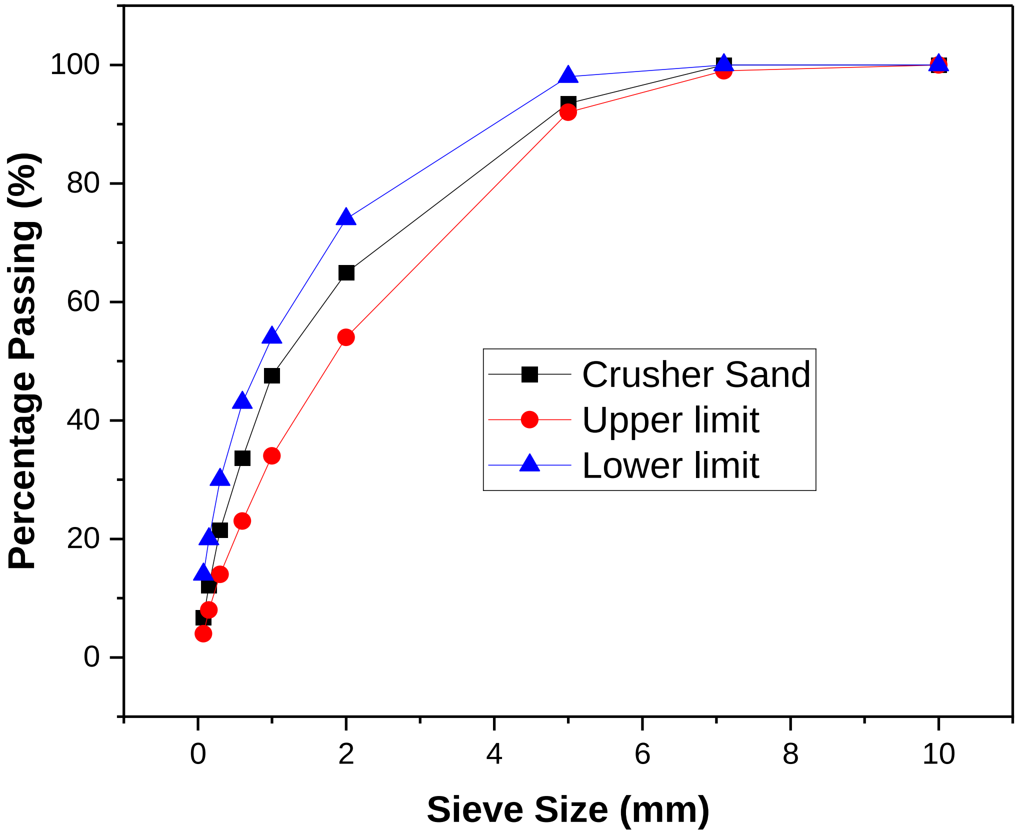


Figure 4.2: Crusher sand grading curve

The well-graded nature of the aggregates will help produce concrete with the desired properties of strength, durability, and resistance to segregation, making it suitable for use in various construction applications.

4.1.4 Mix Design

The characterization of both the coarse and fine aggregates was crucial in developing the mix design that incorporates chicken feathers. These characterizations provided essential information on the properties such as particle size distribution, shape, texture, and specific gravity, all of which influence the concrete mix's workability, strength, and durability. Table 4.3 presented the finalized mix design for 1m³ of concrete, outlining the specific proportions of cement, water, aggregates, and chicken feathers used across all testing scenarios. This detailed mix design ensured consistency in the experimental procedure and allows for accurate comparisons of the effects of varying chicken feather content on concrete properties.

Table 4.3: Mix design for $1m^3$ concrete for all the tests

Mix ID	Chicken feathers Content (kg/m^3)	Water Content (kg/m^3)	Premia 310 (plasticizer) (ml)	Cement Content (kg/m^3)	Fine content (kg/m^3)	Coarse content (kg/m^3)
Mix 1- 0% CF	-	200.5	0	385.513	787.338	909.62
Mix 2- 1% UCF	22.829	237.526	20	385.513	787.338	886.791
Mix 3 -1% TCF	22.829	200.5	0	385.513	787.338	886.791
Mix 4- 0.75% TCF	17.122	200.5	0	385.513	787.338	892.498
Mix 5 -1.25% TCF	28.537	200.5	0	385.513	787.338	881.083

4.2 Slump Test

4.2.1 Analysis of Slump Test Results

This section presents the slump test results for various concrete mixes incorporating both untreated and treated chicken feathers, as shown in Figure 4.3. Higher slump values generally indicate greater fluidity and workability, while lower slump values suggest a stiffer mix, which might be more difficult to work with but potentially offers different structural characteristics. Figure 4.4 shows the initial mix with untreated chicken feathers resulted in a dry mixture with no slump, as the feathers absorbed all the water. After adding a plasticizer, a workable mixture with a noticeable slump was achieved. The superplasticizer reduced the surface tension of the water, allowing for better flow and cohesion between the aggregates and binder. This adjustment, along with careful modifications to the water-to-cement ratio, helped optimize the mixture's performance, ensuring that the concrete could maintain sufficient workability despite the water-absorbing nature of the untreated chicken feathers.

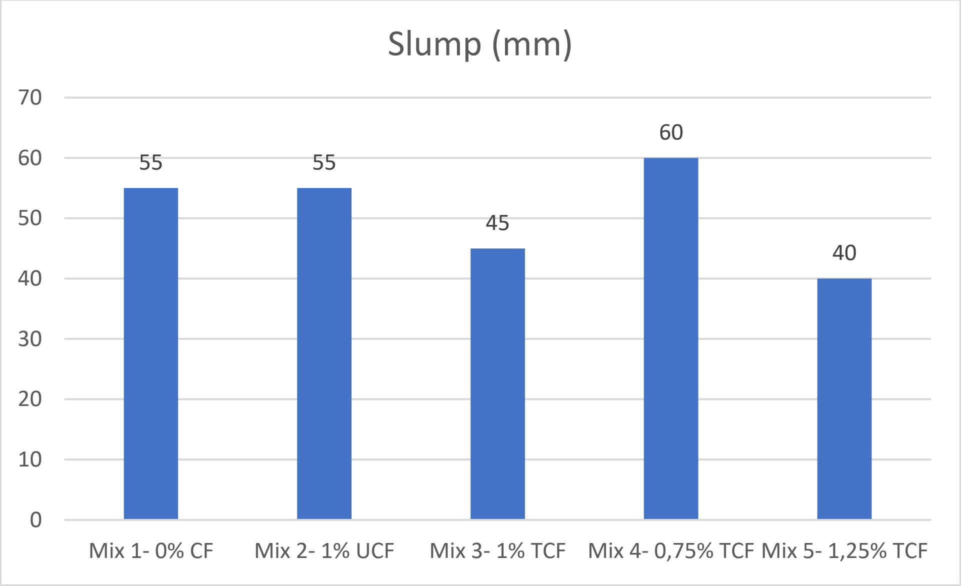


Figure 4.3: Slump test results for all mixes

Figure 4.4: Untreated chicken feathers caused no slump, while adding a plasticizer achieved a noticeable slump

Mix 1- 0% CF– 55 mm Slump: The control mix, has a slump of 55mm. This value serves as the baseline for comparison and represents a moderate level of workability, which is typically suitable for general-purpose concrete applications.

Mix 2- 1% UCF – 55 mm Slump: Shows the same slump as the control mix at 55 mm. This suggests that the inclusion of untreated chicken feathers at this percentage does not significantly alter the concrete's workability compared to the standard mix. This could be due to the fibers lacking sufficient cohesion to significantly interfere with the mix's flow.

Mix 3- 1% TCF – 45 mm Slump: Reduces the slump to 45 mm, indicating decreased workability compared to the control. The treatment process likely enhances the binding properties of the feathers, making the mix stiffer. The specific nature of this treatment may involve chemical modifications that increase the surface roughness or reactivity of the feathers, thereby influencing the interaction with the cement matrix.

Mix 4- 0.75% TCF– 60 mm Slump: Results in the highest observed slump of 60 mm. This increased workability may be attributed to the lower volume of fibers, which allows better flow and dispersion within the mix. This suggests an optimal balance where treated feathers provide some reinforcement without overly compromising fluidity.

Mix 5- 1.25% TCF– 40 mm Slump: Exhibits the lowest slump value of 40mm, indicating significant stiffness and reduced workability. This finding implies that higher concentrations of treated fibers can lead to increased internal friction and reduced fluidity, potentially due to more extensive bonding or entanglement within the mix.

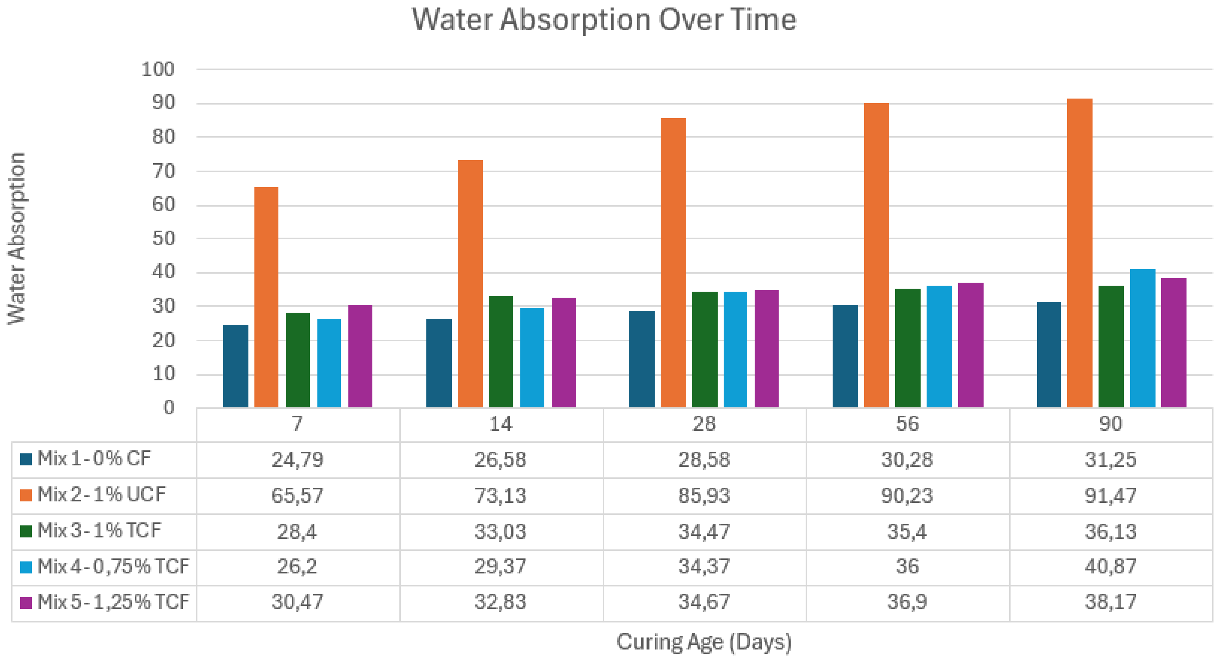
The results indicate that incorporating chicken feathers—particularly when treated—affects the slump values and, consequently, the workability of the concrete mix. Notably, 1% untreated chicken feathers do not significantly alter workability compared to the control, whereas 1% treated feathers reduce it. This suggests that the treatment process modifies the physical or chemical characteristics of the feathers, increasing their interaction with the cement matrix and resulting in a stiffer mix. Supporting this, Toumi (2024) noted that adding less than 2% chicken feather fibers maintains adequate workability, while Sutarno et al. (2021) observed improvements in the mixing process and overall workability with feather addition. Among all mixes, Mix 4 (0.75% treated chicken feathers) achieved the highest workability, evidenced by a 60 mm slump. This indicates an optimal balance between fiber reinforcement and ease of placement, making it suitable for applications requiring both structural performance and practical workability.

The observed reduction in workability of concrete with both treated and untreated chicken feathers aligns with findings from previous studies on natural fiber-reinforced composites. Abrar (2021) reported a significant decrease in slump values when banana fibers were added to concrete, attributing this to the fibers' high water absorption, which reduces the water available for the cement matrix. Similarly, Onuaguluchi and Banthia (2016) noted that plant-based fibers such as sisal, coir, and bamboo decrease workability due to their hydrophilic nature and the presence of hydroxyl groups that enhance moisture absorption. These studies suggest that the decreased fluidity observed in the current work is related to the fibers' surface chemistry, structure, and tendency to form networks that hinder flow. Differences in slump values between treated and untreated fibers may further be explained by fiber treatment, which can alter surface roughness, porosity, and water absorption, thereby influencing interaction with the cement paste. Overall, these comparisons indicate that fiber type, treatment, and dosage are critical factors in determining workability, emphasizing the importance of selecting and preparing fibers carefully to maintain desirable fresh concrete properties.

4.3 Water Absorption

4.3.1 Analysis of Water Absorption Results

The water absorption results for all five concrete mixes, as presented in Figure 4.5, highlight the influence of incorporating both treated and untreated chicken feathers on the curing behaviour and overall performance of the concrete. Measurements were taken at 7, 14, 28, 56, and 90 days to track variations in water absorption over time and to evaluate the long-term effects of feather inclusion on the material's porosity and durability.



	7	14	28	56	90
■ Mix 1 - 0% CF	24,79	26,58	28,58	30,28	31,25
■ Mix 2 - 1% UCF	65,57	73,13	85,93	90,23	91,47
■ Mix 3 - 1% TCF	28,4	33,03	34,47	35,4	36,13
■ Mix 4 - 0,75% TCF	26,2	29,37	34,37	36	40,87
■ Mix 5 - 1,25% TCF	30,47	32,83	34,67	36,9	38,17

Figure 4.5: Water Absorption results for all mixes.

Mix 1- 0% CF, showed a gradual rise in water absorption, increasing from 24.79 on Day 7 to 31.25 by Day 90. This steady progression is typical of well-hydrated concrete, as curing advances, free water leaves the matrix, pores tighten, and the rate of additional absorption slows. The modest overall gain points to low residual porosity and good impermeability—both hallmarks of durable concrete.

Mix 2- 1% UCF**,** registered the highest absorption values of all five blends, climbing from 65.57 on Day 7 to 91.47 on Day 90. Untreated feathers retain their natural hydrophilic surfaces and hollow shafts, drawing in and holding water. The persistently elevated absorption indicates a highly porous interfacial transition zone around the fibres, which can invite water ingress, accelerate freeze-thaw damage, and reduce resistance to chemical attack over time.

Mix 3- 1% TCF, the early-age absorption started much lower—28.40 on Day 7—and rose to 36.13 by Day 90. Treatment reduces the feathers' ability to wick water, resulting in a denser interfacial transition zone and a more controlled moisture profile. The moderate uptake suggests sufficient internal moisture for hydration while keeping total porosity in check, supporting both strength development and durability.

Mix 4- 0.75% TCF**, a**bsorption values moved from 26.20 on Day 7 to 40.87 on Day 90. The slightly larger increase (relative to Mix 3- 1% TCF) points to an optimal balance: fewer fibres mean better dispersion and less chance of forming continuous pore channels, yet enough surface area remains to retain curing water. The result is good workability, efficient hydration, and an overall tight pore structure.

Mix 5- 1.25% TCF, this higher-fibre blend opened at 30.47 on Day 7 and reached 38.17 by Day 90. Although its final absorption is comparable to Mix 3- 1% TCF, the higher fibre count can hinder flow and consolidation, potentially leaving isolated voids. Even so, the treated feathers kept long-term absorption in a moderate range, suggesting acceptable durability provided adequate compaction is ensured.

Concrete reinforced with untreated chicken feathers exhibited significantly higher water absorption compared to the control, consistent with Sutarno et al. (2021), who reported that raw keratin fibers are hydrophilic and porous. The poor bonding between untreated feathers and the cement matrix likely promotes microvoid formation, increasing water uptake. In contrast, surface treatment of the feathers substantially reduced absorption, in line with Pavithra et al. (2021), who noted that modified keratin fibers display a dual hydrophilic–hydrophobic nature that improves matrix compatibility. Among the treated mixes, Mix 4 (0.75% TCF) showed the lowest early-age absorption and a balanced long-term profile, indicating an optimal combination of workability, hydration, and impermeability. Elevated absorption in Mix 2 (1% UCF) underscores the risk of higher permeability and reduced durability if untreated fibers are used. These results are further supported by Jamshaid et al. (2022), who found that treated natural fibers reduce water absorption while untreated fibers increase it. Overall, the findings demonstrate that fiber treatment—not merely fiber content—is the key factor governing water absorption, allowing treated chicken feathers to be safely incorporated into concrete without compromising durability.

4.4 Compressive Strength

4.4.1 Analysis of Compressive Strength Test Results

The compressive strength results for all five concrete mixes, tested at 7, 14, 28, 56, and 90 curing days, are shown in Figure 4.6. The figure illustrates the effect of varying amounts of treated and untreated chicken feathers on the strength development of concrete over time.

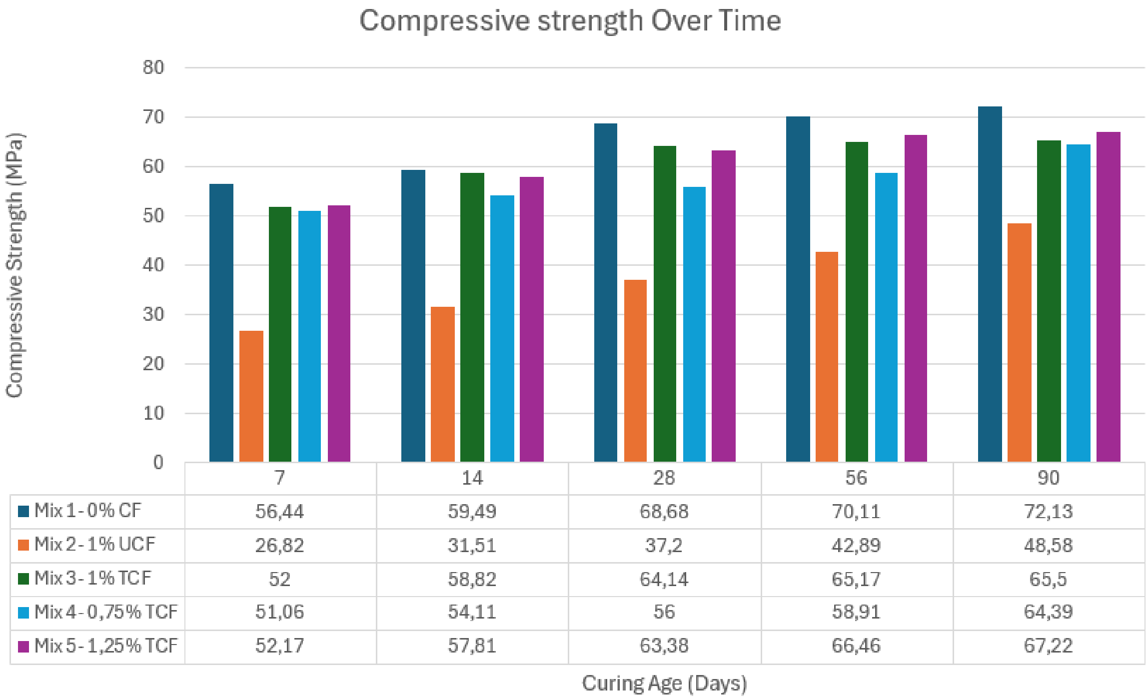


Figure 4.6: Compression Strength results for all mixes

As the control mix, Mix 1- 0% CF displayed a steady increase in compressive strength from 56.44 MPa at 7 days to 72.13 MPa at 90 days. This consistent growth signified effective curing and optimal hydration, which are crucial for achieving high strength. Mix 1- 0% CF maintained the highest compressive strength throughout the test period, demonstrating that the absence of added organic materials results in superior strength development.

Mix 2- 1% UCF showed the lowest compressive strength, beginning at 26.82 MPa and increasing to 48.58 MPa by 90 days. The low strength observed may be due to the untreated chicken feathers, which can decay over time, leading to voids or weakened concrete structure. This decay process can interfere with cement hydration, adversely affecting strength development. The presence of untreated organic material may also introduce byproducts that further compromise concrete performance.

Mix 3- 1% TCF exhibited improved compressive strength compared to Mix 2- 1% UCF, with values increasing from 52.00 MPa at 7 days to 65.50 MPa at 90 days. The treatment of the chicken feathers likely reduced the negative impact of organic decomposition, enhancing the mix's strength. The treatment process could include methods that stabilize the feathers, preventing decay and improving their interaction with the cement matrix.

Mix 4- 0.75% TCF showed slightly lower compressive strength than Mix 3- 1% TCF, starting at 51.06 MPa and reaching 64.39 MPa by 90 days. The reduced feather content compared to Mix 3- 1% TCF might account for the marginally lower strength, although it still outperformed Mix 2- 1% UCF. The results suggest that while treated feathers improve strength, there is an optimal concentration for achieving the best results.

Mix 5- 1.25% TCF’s compressive strength was comparable to Mix 3- 1% TCF, beginning at 52.17 MPa and increasing to 67.22 MPa by 90 days. The higher feather content, although treated, seemed to positively impact strength, demonstrating better performance than Mix 4- 0.75% TCF. This suggested that increasing the proportion of treated feathers can enhance strength, although care must be taken to avoid potential negative effects from excessively high concentrations.

This study investigated the effects of untreated and treated chicken feathers on the compressive strength of concrete. Results showed that untreated chicken feathers significantly reduced early-age compressive strength due to their organic nature, which leads to decay, void formation, and disruption of the cement hydration process. Mix 2- 1% UCF, containing untreated feathers, recorded an initial strength of 26.82 MPa, which increased to 48.58 MPa at 90 days—indicating some delayed strength recovery, yet still underperforming compared to the control mix. In contrast, Mix 1- 0% CF, which excluded chicken feathers, consistently achieved the highest strength at 57.12 MPa, underscoring the integrity of traditional concrete formulations.

The results of this study align closely with trends reported in the natural-fiber concrete literature. Untreated chicken feathers significantly reduced early-age compressive strength, with Mix 2 – 1% UCF showing the lowest values (26.82 → 48.58 MPa), consistent with findings that untreated organic fibers can decay, form voids, and disrupt cement hydration, thereby weakening the concrete structure (Sutarno et al., 2021). In contrast, treated chicken feathers improved performance, as observed in Mix 3 – 1% TCF, Mix 4 – 0.75% TCF, and Mix 5 – 1.25% TCF, which recorded higher compressive strengths relative to the untreated mix. This improvement supports literature evidence that fiber treatment enhances fiber–matrix bonding and reduces degradation, allowing better stress transfer and mitigating strength losses (Jamshaid et al., 2022). Optimal fiber content effects were observed, with moderate feather dosages (around 1–1.25%) yielding the best performance, in agreement with reports that low-to-moderate natural-fiber content can maintain or modestly enhance compressive strength, while higher or poorly dispersed contents may reduce strength (Vijayalakshmi et al., 2023). Conventional concrete without added organic fibers (Mix 1 – 0% CF) consistently achieved the highest compressive strength (56.44 → 72.13 MPa), reinforcing observations that natural-fiber concretes rarely surpass the performance of standard mixes, particularly at early ages (Vijayalakshmi et al., 2023). Overall, these findings underscore the importance of proper material treatment and careful mix design when incorporating organic fibers into concrete and highlight the potential for treated fibers to provide acceptable performance within a defined optimal range.

4.4.2 Statistical Analysis for Compressive Strength

To determine whether the differences in compressive strength between Mix 1- 0% CF (the baseline) and the other mixes were statistically significant, an Analysis of Variance (ANOVA) was performed at a 95% confidence level. As shown in Table 4.4, a p-value less than 0.05 was considered statistically significant, indicating that the observed differences in compressive strength were unlikely to have occurred by chance. Conversely, p-values equal to or greater than 0.05 suggested that the differences were not statistically significant.

Table 4.4: Statistical Analysis of Compressive Strength Comparison Across Different Mixes at Various Curing Periods

Curing Period	**Mix Comparison**	**p-value**	**Significance Status**
7 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.004	Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.03	Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.50	Not Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.02	Significant
14 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.0001	Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.09	Not Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.045	Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.032	Significant
28 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.12	Not Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.04	Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.30	Not Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.06	Not Significant
56 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.20	Not Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.04	Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.50	Not Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.02	Significant
90 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.17	Not Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.01	Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.20	Not Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.03	Significant

The significant differences observed between Mix 1- 0% CF and Mix 2- 1% UCF (at 7 and 14 days) highlighted that the 1% untreated material in Mix 2- 1% UCF results in a considerable decrease in strength compared to the control mix (Mix 1- 0% CF), demonstrating its less effective impact. On the other hand, significant differences between Mix 1- 0% CF and Mix 3- 1% TCF (across all curing periods) suggest that the 1% treated material in Mix 3- 1% TCF consistently enhances strength, showing a beneficial effect over time. Additionally, significant results for Mix 1- 0% CF versus Mix 5- 1.25% TCF at 56 and 90 days indicate that the 1.25% treated material in Mix 5- 1.25% TCF leads to improved strength in the long term. Overall, the significant results reveal that higher treatment percentages, particularly 1% and 1.25%, contribute to increased strength, with notable improvements especially at early curing stages.

In contrast, the absence of significant differences between Mix 1- 0% CF and Mix 4- 0.75% TCF at 7 and 28 days indicated that the 0.75% treated material in Mix 4- 0.75% TCF does not offer a notable improvement in strength compared to the control mix, particularly in the early and mid-curing stages. Similarly, the lack of significant difference between Mix 1- 0% CF and Mix 2- 1% UCF at 28, 56, and 90 days suggests that the untreated mix (Mix 2- 1% UCF) does not show lasting strength improvements over time. These not significant results suggest that lower treatment levels (such as 0.75%) and untreated mixes provide little to no long-term strength enhancement.

4.5 Split Tensile Strength Test

4.5.1 Analysis of Tensile Strength Results

The data provided in Figure 4.7 summarized the tensile strength results (in MPa) of five different concrete mixes, measured at intervals of 7, 14, 28, 56, and 90 curing days.

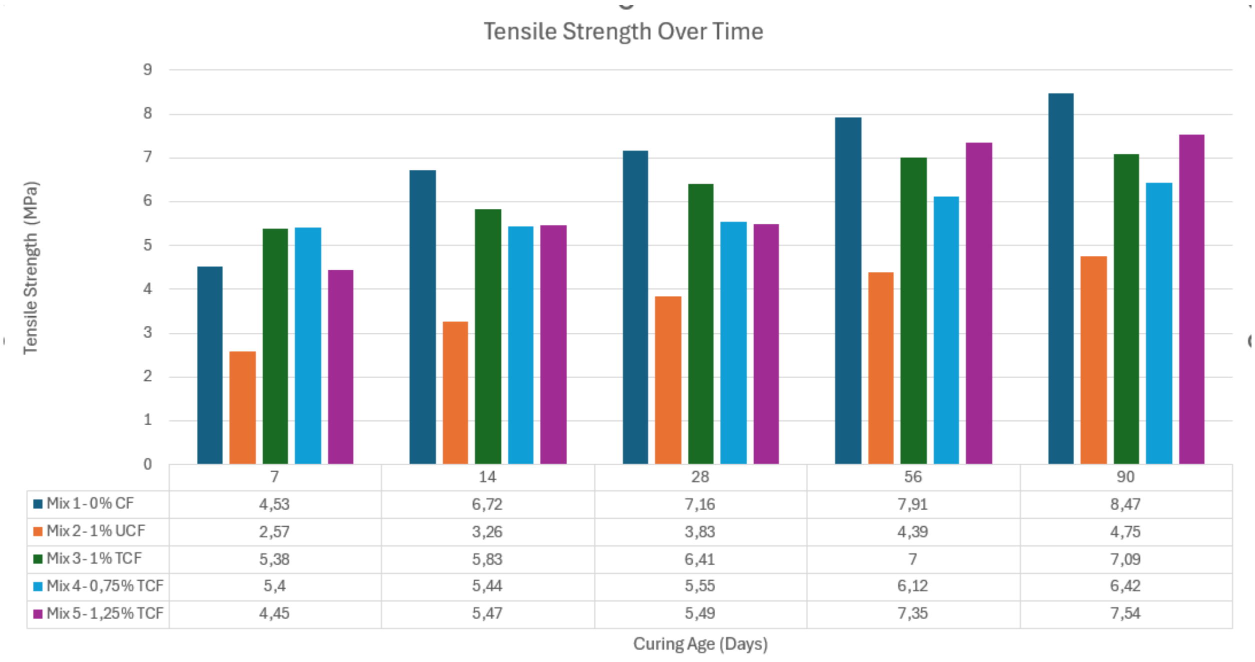


Figure 4.7: Tensile strength results for all mixes

Mix 1- 0% CF, showed a consistent increase in tensile strength over time. It had the highest tensile strength at each interval, reaching 8.47 MPa at 90 days. Mix 2- 1% UCF, had the lowest tensile strength among all mixes. Its progression was slower, ending at 4.75 MPa after 90 days. Treated chicken feathers appeared to offer improved tensile strength over untreated feathers. Mix 3- 1% TCF, with 1% treated chicken feathers, performed better than Mix 2- 1% UCF, with a final tensile strength of 7.09 MPa at 90 days. Mix 4- 0.75% TCF, containing 0.75% treated chicken feathers, had steady growth, reaching 6.42 MPa by 90 days. Mix 5- 1.25% TCF, exhibited similar results to Mix 3- 1% TCF, with a final tensile strength of 7.54 MPa. The results indicated that untreated chicken feathers led to a significant reduction in tensile strength, suggesting an adverse impact on the concrete matrix's integrity. Conversely, the use of treated chicken feathers demonstrated promising outcomes, with Mix 3- 1% TCF exhibiting tensile strength results close to the baseline concrete at 90 days. Furthermore, Mix 5- 1.25% TCF, which contained a higher percentage of treated feathers, also showed satisfactory strength development over time.

In this study, the tensile strength results demonstrated clear trends related to the presence and treatment of chicken feathers in concrete. The control mix, Mix 1-0% CF, consistently exhibited the highest tensile strength at all intervals, reaching 8.47 MPa at 90 days, aligning with literature that unmodified concrete generally achieves superior tensile performance due to the absence of organic materials that might interfere with cement hydration and compromise matrix integrity (Momoh et al., 2022). In contrast, Mix 2-1% UCF, which contained untreated chicken feathers, recorded the lowest tensile strength, ending at 4.75 MPa after 90 days. This reduction corresponds with findings in previous studies where untreated natural fibers negatively affected tensile strength, primarily due to organic decay, void formation, and weak fiber–matrix interactions that impede effective stress transfer (Shah et al., 2022). Treated chicken feathers, however, showed a marked improvement in tensile performance. Mix 3-1% TCF and Mix 5-1.25% TCF reached 7.09 MPa and 7.54 MPa at 90 days, respectively, suggesting that proper treatment stabilizes the feathers, mitigates decay, and enhances fiber–matrix bonding, allowing for better load transfer and crack-bridging, consistent with literature emphasizing the role of fiber treatment in tensile enhancement (Momoh et al., 2022). Mix 4-0.75% TCF, containing a lower percentage of treated feathers, achieved 6.42 MPa, indicating that while treated fibers improve strength, there is an optimal content for maximizing tensile benefits, as excessively low or high contents can limit crack-bridging efficiency or reduce workability (Lumingkewas et al., 2017). Overall, the results highlight that treated chicken feathers can effectively reinforce concrete, with tensile strength outcomes approaching that of the control mix, demonstrating the potential for properly processed natural fibers to serve as viable sustainable additives in concrete applications.

4.5.2 Statistical Analysis for Tensile Strength

Statistical analysis was conducted to compare the tensile strength of various concrete mixes (Mix 1- 0% CF, Mix 2- 1% UCF, Mix 3- 1% TCF, Mix 4- 0.75% TCF, and Mix 5- 1.25% TCF) at different curing periods (7, 14, 28, 56, and 90 days). The objective was to assess whether the differences in tensile strength among the mixes were statistically significant, thereby identifying the mix formulation that provides the best performance over time. The results are presented in Table 4.5.

Table 4.5: Statistical Analysis of Tensile Strength Comparison Across Different Mixes at Various Curing Periods

Curing Period	Mix Comparison	p-value	Significance Status
7 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.0045	Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.04	Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.52	Not Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.03	Significant
14 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.0002	Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.092	Not Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.044	Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.034	Significant
28 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.14	Not Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.042	Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.33	Not Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.062	Not Significant
56 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.21	Not Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.042	Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.50	Not Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.022	Significant
90 Days	Mix 1- 0% CF vs Mix 2- 1% UCF	0.17	Not Significant
	Mix 1- 0% CF vs Mix 3- 1% TCF	0.01	Significant
	Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.25	Not Significant
	Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.032	Significant

The results of the mix comparisons across various curing periods revealed insights into the statistical differences in performance between Mix 1- 0% CF and the other mixes, which were formulated with varying amounts of chicken feathers. Mix 1- 0% CF served as the reference mix with 0% chicken feathers, while the other mixes incorporated treated and untreated chicken feathers at different percentages: 1% untreated chicken feathers, 1% treated chicken feathers, 0.75% treated chicken feathers, and 1.25% treated chicken feathers.

At the 7-day curing period, Mix 1- 0% CF demonstrated significant differences with Mix 2- 1% UCF, Mix 3- 1% TCF, and Mix 5- 1.25% TCF. This suggested that the incorporation of untreated and treated chicken feathers affected the early properties of the mix, particularly the treated feathers. However, no significant difference was observed between Mix 1- 0% CF and Mix 4- 0.75% TCF, indicating that the performance of the mix with a moderate amount of treated chicken feathers closely resembled that of the reference mix during the initial curing phase.

As curing progressed to 14 days, significant differences persisted between Mix 1- 0% CF and Mix 2- 1% UCF, Mix 4- 0.75% TCF, and Mix 5- 1.25% TCF. This highlighted the continued influence of both untreated and treated chicken feathers on the mix's properties, with Mix 3- 1% TCF showing no significant difference from Mix 1- 0% CF. This suggested that the treated feathers in this proportion might have begun to develop similar characteristics to the reference mix after two weeks of curing, whereas higher amounts of treated feathers (Mix 5- 1.25% TCF) and untreated feathers (Mix 2- 1% UCF) continued to show distinct properties.

At the 28-day curing period, the number of significant differences decreased, and Mix 1- 0% CF only showed a significant difference with Mix 3- 1% TCF. Comparisons with Mix 2- 1% UCF, Mix 4- 0.75% TCF, and Mix 5- 1.25% TCF were not significant, implying that the mixes were becoming more comparable in performance. The effect of the chicken feathers, particularly at moderate levels of treated chicken feathers (Mix 4- 0.75% TCF), had diminished, allowing the mixes to stabilize. By the 56-day curing period, Mix 1- 0% CF retained significant differences with Mix 3- 1% TCF and Mix 5- 1.25% TCF, while Mix 2- 1% UCF and Mix 4- 0.75% TCF showed no significant difference from Mix 1- 0% CF. This suggested that mixes with higher amounts of treated chicken feathers still exhibited distinct characteristics after prolonged curing, while those with moderate or lower amounts of treated feathers converged with the reference mix. Finally, at the 90-day curing period, Mix 1- 0% CF again showed significant differences with Mix 3- 1% TCF and Mix 5, consistent with earlier findings. The comparisons with Mix 2- 1% UCF and Mix 4- 0.75% TCF remained not significant, indicating that these mixes with moderate or lower chicken feather content had fully stabilized and now performed similarly to Mix 1- 0% CF after extended curing.

The analysis revealed significant differences between mixes incorporating chicken feathers and a reference mix, particularly at higher feather content. Notably, mixes with 1% untreated and 1.25% treated chicken feathers (Mix 2- 1% UCF and Mix 5- 1.25%

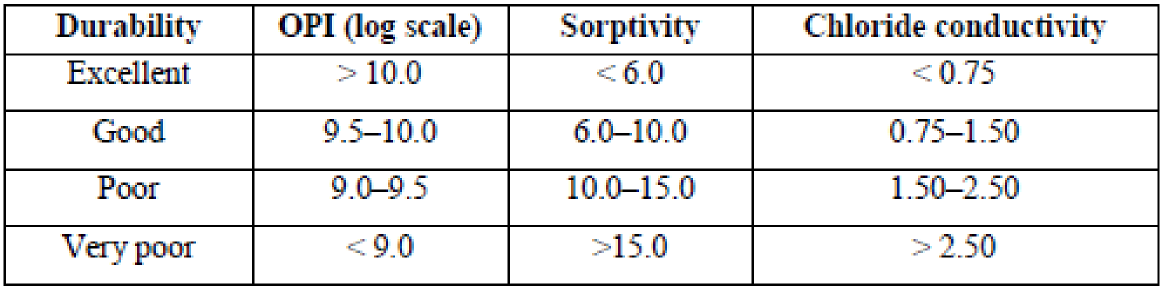
TCF) demonstrated persistent performance differences across all curing periods, suggesting that feather type and content influence early curing behavior. Conversely, mixes with moderate levels of treated chicken feathers (Mix 3- 1% TCF and Mix 4- 0.75% TCF) showed a convergence with the reference mix over time, indicating that the treatment and quantity of chicken feathers had a more pronounced effect in the early stages of curing but became less influential as curing progressed. These findings point to the potential for optimizing treated chicken feather content in concrete mixtures to meet specific performance objectives. Supporting research by Pavithra et al. (2021) corroborated these findings, demonstrating that the inclusion of chicken feather fibers can positively affect the mechanical properties of concrete, particularly split tensile strength. The study highlighted the importance of fiber content optimization for enhancing concrete's mechanical performance.

4.6 Durability Test Results

The durability of concrete reinforced with chicken feathers remains an under-researched area, with no available literature specifically addressing this topic. While many studies have focused on the durability of fiber-reinforced concrete, including various types of natural and synthetic fibers, none appear to address the inclusion of chicken feathers as a reinforcement material. The unique properties of chicken feathers, such as their organic nature and potential for degradation over time, make it difficult to directly draw comparisons or cite studies from other types of fiber-reinforced concrete. As a result, the lack of existing research on the specific durability tests for chicken feather-reinforced concrete means there is no available literature to reference in relation to its long-term behavior under various environmental conditions.

The results of the durability indexes tests (Oxygen Permeability Index (OPI), sorptivity, and chloride ion penetration) were analyzed and discussed based on the indicators presented in Table 4.6. When the OPI was excellent, it indicated very low permeability to oxygen, suggesting that the concrete was dense and well-compacted. Concrete with good durability typically shows a high Oxygen Permeability Index (OPI), which is associated with low sorptivity, and low chloride penetration.

Table 4.6: Classification of Durability Indicators (Alexander et al., 2001)



Durability	OPI (log scale)	Sorptivity	Chloride conductivity
Excellent	> 10.0	< 6.0	< 0.75
Good	9.5–10.0	6.0–10.0	0.75–1.50
Poor	9.0–9.5	10.0–15.0	1.50–2.50
Very poor	< 9.0	>15.0	> 2.50

4.6.1 Oxygen permeability index

Table 4.7 summarized the Oxygen Permeability Index (OPI) results at 28, 56, and 90 days for concrete mixes incorporating varying percentages and treatments of chicken feathers.

Table 4.7: The Oxygen Permeability Index (OPI) results for concrete mixes at 28, 56, and 90 days.

	OPI					
Mix Description	**28 Days**		**56 Days**		**90 Days**	
Mix 1- 0% CF	10.07	Excellent	10.06	Excellent	10.19	Excellent
Mix 2- 1% UCF	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Mix 3 -1% TCF	9.9	Good	9.84	Good	9.95	Good
Mix 4- 0.75% TCF	9.89	Good	9.71	Good	9.73	Good
Mix 5 -1.25% TCF	10.14	Excellent	10.3	Excellent	10.05	Excellent

4.6.1.1 Oxygen Permeability Index results (28 Days)

Mix 1- 0% CF, achieved an OPI of 10.07, establishing a baseline for comparison. Mix 2- 1% UCF, produced an invalid result, indicating possible inconsistencies in the mixture or testing procedure. In contrast, Mix 3- 1% TCF and Mix 4- 0.75% TCF, demonstrated strong performance with OPI scores of 9.9 and 9.89. Significantly, Mix 5- 1.25% TCF, attained the highest OPI of 10.14, suggesting that higher proportions of treated feathers may further enhance concrete performance when carefully controlled.

These findings underscore the potential of treated chicken feathers as a sustainable fibre reinforcement that improves concrete strength and durability. The invalid outcome for the untreated mix emphasizes the necessity of appropriate treatment to ensure material reliability.

4.6.1.2 Oxygen Permeability Index results (56 Days)

The base concrete mix without additives (Mix 1- 0% CF) demonstrated excellent performance with a high OPI score of 10.06, affirming its robustness and consistency over time. Conversely, Mix 2- 1% UCF consistently yielded invalid OPI results at both 28 and 56 days. This suggests significant compatibility challenges with untreated feathers, likely due to poor integration or disruptive interactions within the concrete matrix.

Mixes incorporating treated chicken feathers——exhibited valid and favorable OPI results. Mix 3- 1% TCF and Mix 4- 0.75% TCF recorded OPI scores of 9.84 and 9.71, respectively, indicating good durability despite a slight decrease from earlier measurements. Notably, Mix 5- 1.25% TCF achieved the highest OPI score of 10.3, suggesting that a higher proportion of treated feathers may enhance or sustain concrete durability over extended curing periods. These findings underscore the potential of treated chicken feathers as a viable additive for improving concrete performance, while simultaneously addressing environmental sustainability through the utilization of poultry by-products.

4.6.1.3 Oxygen Permeability Index (90 Days)

Mix 1- 0% CF performed excellently, achieving an OPI score of 10.19, confirming the reliability and stability of the standard mix over an extended curing period. Mix 2- 1% UCF, consistently produced invalid results, highlighting ongoing issues with untreated fibres. This suggests that untreated feathers may be incompatible or inconsistent in the concrete mix, affecting the material's overall performance.

Mix 3- 1% TCF and Mix 4- 0.75% TCF, demonstrated good performance with OPI scores of 9.95 and 9.73, respectively. Although these results were slightly lower than the 56-day tests, they still indicated the beneficial impact of treated fibres. The minor decline in performance over time could reflect the concrete's maturation or other long-term factors influencing the fibre’s effect. Mix 5- 1.25% TCF, maintained an excellent OPI score of 10.05, suggesting that higher percentages of treated feathers can sustain or even enhance concrete performance, offering long-term benefits.

4.6.1.4 Oxygen Permeability Index results (28,56 and 90 Days)

28-Day Results: The mix with 1.25% treated chicken feathers demonstrated strong early strength, achieving an OPI score of 10.14. In contrast, the mix with 1% untreated feathers produced invalid results, likely due to poor adhesion or hydration issues.

56-Day Results: The 1.25% treated feathers mix continued to show excellent performance, with an OPI score of 10.3, reflecting continued strength and durability. The mix with untreated feathers remained invalid, confirming the negative impact of untreated fibres on concrete quality.

90-Day Results: The 1.25% treated feathers mix maintained an OPI score of 10.05, demonstrating sustained performance over time. The baseline mix (0% feathers) also showed excellent performance, underscoring its inherent strength.

Treated chicken feathers, particularly at a 1.25% concentration, positively influence concrete's strength and durability. The treatment process enhances the compatibility of the feathers with the concrete matrix, improving bonding and hydration. In contrast, untreated chicken feathers consistently resulted in invalid results, highlighting the importance of proper treatment.

The study revealed that the incorporation of coconut fibres significantly influenced the transport properties of concrete, with both fibre treatment and dosage playing crucial roles. The control mix (0% CF) exhibited very low sorptivity and excellent oxygen permeability index (OPI) across all ages, consistent with literature indicating that plain concrete with a dense microstructure minimizes water ingress and oxygen diffusion (Chen et al., 2017). In contrast, the 1% untreated coconut fibre (UCF) mix performed very poorly, showing high sorptivity and invalid OPI readings, which aligns with studies reporting that untreated natural fibres increase porosity and create microchannels that compromise transport properties (Luo et al., 2021). Treated coconut fibres (TCF) showed improved performance: the 1% TCF and 0.75% TCF mixes exhibited moderate sorptivity and slightly reduced OPI compared to the control, reflecting the beneficial effects of fibre treatment in reducing interfacial transition zone (ITZ) porosity and limiting water and oxygen pathways (Valcuende et al., 2021). Interestingly, the 1.25% TCF mix demonstrated excellent sorptivity and high OPI, surpassing the 1% TCF mix, which suggests an optimal fibre dosage can enhance durability by bridging microcracks and minimizing connected porosity while the treatment ensures good fibre–matrix bonding (Lim et al., 2018). Overall, the findings underscore that untreated natural fibres can severely compromise concrete durability, while treated fibres, particularly at appropriate dosages, can maintain or even improve transport-related properties.

4.6.2 Sorptivity Test Results

The 28-day Sorptivity test results for concrete mixes incorporating varying percentages and treatments of chicken feathers are presented in Table 4.8. These results provide insights into the performance of the concrete over 28, 56, and 90 days, showcasing the effects of chicken feather inclusion and treatment on the sorptivity of the mixes.

Table 4.8: The 28-day Sorptivity test results for concrete mixes

	Sorptivity test results					
Mix Description	**28 Days**		**56 Days**		**90 Days**	
Mix 1- 0% CF	5.03	Excellent	4.32	Excellent	4.65	Excellent
Mix 2- 1% UCF	21.73	Very Poor	17.95	Very Poor	24.92	Very Poor
Mix 3 -1% TCF	8.4	Good	9.25	Good	6.8	Good
Mix 4- 0.75% TCF	9.79	Good	6.3	Good	9.27	Good
Mix 5 -1.25% TCF	3.91	Excellent	4.12	Excellent	3.89	Excellent

4.6.2.1 Sorptivity test results (28 Days)

Upon analyzing the 28-day Sorptivity test results for the five concrete mixes containing varying percentages and treatments of chicken feathers, several significant observations and conclusions can be made. Mix 1- 0% CF, serving as the control without any chicken feathers (0% additive), exhibited an excellent Sorptivity value of 5.03. This low sorptivity indicated effective resistance to water penetration, highlighting the inherent quality of the base concrete mixture in preventing moisture ingress.

Mix 2- 1% UCF, recorded a significantly higher Sorptivity value of 21.73, categorized as very poor. This result underscored the detrimental effect of untreated feathers on concrete performance, as evidenced by increased water absorption rates, potentially compromising the material's durability and longevity. Mix 3- 1% TCF and Mix 4- 0.75% TCF, demonstrated Sorptivity values of 8.4 and 9.79, both classified as good. These results suggested that treated chicken feathers contribute positively to reducing water absorption compared to the untreated mix, although there is a slight variance in performance depending on the percentage used. Mix 5- 1.25% TCF, exhibited the lowest Sorptivity value of 3.91, indicating excellent resistance to water penetration. This suggested that higher percentages of treated feathers further enhance the concrete's ability to repel moisture, potentially improving its durability and resistance to environmental factors.

Mix 1- 0% CF’s excellent Sorptivity value confirmed the effectiveness of the base concrete mix in preventing water ingress, serving as a reliable benchmark for comparison. The extremely high Sorptivity value for Mix 2- 1% UCF highlights the adverse impact of untreated chicken feathers, emphasizing the necessity of proper treatment to maintain concrete performance. Mix 3- 1% TCF and Mix 4- 0.75% TCF showed good performance in Sorptivity tests, indicating that treated chicken feathers can mitigate water absorption to a reasonable extent, although not as effectively as the control mix. Mix 5- 1.25% TCF demonstrated the best performance in reducing Sorptivity, suggesting that higher percentages of treated feathers offer superior water resistance benefits.

The Sorptivity test results underscored the importance of treating additives like chicken feathers to enhance concrete performance. Treated feathers show potential in reducing water absorption and improving durability compared to untreated counterparts. While higher percentages of treated feathers contribute to better water resistance, there may be optimal ranges that balance performance improvements with cost-effectiveness. Future research could focus on refining treatment methods, optimizing additive percentages, and evaluating long-term durability under various environmental conditions to further enhance the sustainability and resilience of concrete mixes using poultry by-products. These findings provide valuable insights into advancing construction materials towards more efficient and environmentally friendly solutions.

4.6.2.2 Sorptivity test (56 Days)

Upon analyzing the 56-day Sorptivity test results for the five concrete mixes containing varying percentages and treatments of chicken feathers, several important observations and conclusions emerge. Mix 1- 0% CF, maintained an excellent Sorptivity value of 4.32. This low sorptivity indicates effective resistance to water penetration, highlighting the durability and quality of the base concrete mixture in preventing moisture ingress over an extended period.

Mix 2- 1% UCF, recorded a Sorptivity value of 17.95, categorized as very poor. This result underscored the detrimental impact of untreated additives on concrete performance, significantly increasing water absorption rates and potentially compromising the material's long-term durability. Mix 3- 1% TCF and Mix 4- 0.75% TCF, demonstrated Sorptivity values of 9.25 and 6.3, both classified as good. These results suggested that treated chicken feathers contribute positively to reducing water absorption compared to untreated mixes, albeit with some variation in performance depending on the treated feather percentage used. Mix 5- 1.25% TCF, showed the lowest Sorptivity value of 4.12, indicating excellent resistance to water penetration. This suggests that higher percentages of treated feathers further enhance the concrete's ability to repel moisture, potentially improving its durability and resilience against environmental factors.

Mix 1- 0% CF’s consistent excellent Sorptivity value reaffirmed the base concrete mix's effectiveness in preventing water ingress, providing a stable benchmark for comparison. The very poor Sorptivity value for Mix 2- 1% UCF highlights the severe impact of untreated chicken feathers on concrete performance, emphasizing the critical need for proper treatment to maintain structural integrity. Mix 3- 1% TCF and Mix 4- 0.75% TCF demonstrated good performance in Sorptivity tests, indicating that treated chicken feathers effectively mitigate water absorption, though not as effectively as the control mix. Mix 5- 1.25% TCF continued to show the best performance in reducing Sorptivity, suggesting that higher percentages of treated feathers offer superior water resistance benefits, potentially enhancing the concrete's durability under various environmental conditions.

The Sorptivity test results underscore the significant role of treated chicken feathers as a beneficial additive for improving concrete performance, particularly in terms of water resistance. Treated feathers are promising in reducing water absorption and enhancing durability compared to untreated counterparts. Future research could explore further optimization of treatment methods, fine-tuning additive percentages, and evaluating long-term performance to maximize the sustainability and resilience of concrete mixes incorporating poultry by-products. These findings contribute valuable insights into advancing construction materials towards more efficient and environmentally friendly solutions, potentially reducing maintenance costs and extending the lifespan of infrastructure.

4.6.2.3 Sorptivity test (90 Days)

Upon analyzing the 90-day Sorptivity test results for the five concrete mixes containing varying percentages and treatments of chicken feathers, several important insights can be drawn. Mix 1- 0% CF, maintained an excellent Sorptivity value of 4.65. This low sorptivity indicated strong resistance to water penetration, highlighting the durability and effectiveness of the base concrete mixture in preventing moisture ingress over an extended curing period. Mix 2- 1% UCF, exhibited a Sorptivity value of 24.92, categorized as very poor. This result underscored the detrimental impact of untreated additives on concrete performance, significantly increasing water absorption rates and potentially compromising the material's long-term structural integrity. Mix 3- 1% TCF and Mix 4- 0.75% TCF, demonstrated Sorptivity values of 6.8 and 9.27, both classified as good. These results indicated that treated chicken feathers contributed positively to reducing water absorption compared to the untreated mix, though there is some variation in performance depending on the treated feather percentage used. Mix 5- 1.25% TCF, recorded the lowest Sorptivity value of 3.89, indicating excellent resistance to water penetration. This suggested that higher percentages of treated feathers further enhance the concrete's ability to repel moisture, potentially improving its long-term durability and resilience against environmental factors.

Mix 1- 0% CF consistently demonstrated excellent Sorptivity values across all time points, reinforcing the reliability and effectiveness of the base concrete mix without additives. Mix 2- 1% UCF's very poor Sorptivity value highlighted the critical importance of proper treatment of additives like chicken feathers to maintain concrete performance and durability.

Mix 3- 1% TCF and Mix 4- 0.75% TCF showed good performance in Sorptivity tests, indicating that treated chicken feathers effectively mitigate water absorption, albeit with varying degrees of effectiveness compared to the control mix. Mix 5- 1.25% TCF continued to exhibit the best performance in reducing Sorptivity, suggesting that higher percentages of treated feathers offer superior water resistance benefits and enhanced long-term durability.

The Sorptivity test results underscored the significant impact of treated chicken feathers as a beneficial additive for improving concrete performance, particularly in terms of water resistance and durability. Treated feathers is promising in reducing water absorption and enhancing the concrete's resilience against moisture, compared to untreated counterparts which significantly compromise performance. Future research could focus on further optimizing treatment methods, refining additive percentages, and evaluating the material's performance under diverse environmental conditions to maximize sustainability and extend infrastructure lifespan. These findings contribute valuable insights into advancing construction materials towards more efficient and environmentally friendly solutions, potentially reducing maintenance costs and improving infrastructure longevity.

4.6.2.4 Sorptivity test (28,56 and 90 Days)

Based on the sorptivity test results of the concrete mixes over 28, 56, and 90 days, several observations can be made regarding the impact of adding untreated and treated chicken feathers as additives. Firstly, looking at the 28-day results, the mix without chicken feathers exhibited excellent sorptivity, indicating minimal water absorption, which is desirable for concrete durability. In contrast, the mix containing 1% untreated chicken feathers showed very poor sorptivity, significantly increasing water absorption. This suggested that untreated feathers may adversely affect concrete performance in terms of water ingress and potentially long-term durability. However, when the feathers were treated, the results varied. The 1% treated chicken feather mix showed good sorptivity, similar to the 0.75% treated mix, which also performed well. Interestingly, the 1.25% treated chicken feather mix exhibited excellent sorptivity, even outperforming the control mix without feathers. This indicated that properly treated feathers can potentially enhance concrete performance by reducing water permeability, especially at higher concentrations. Moving to the 56-day results, similar trends were observed. The control mix maintained excellent sorptivity, while the 1% untreated feather mix continued to show very poor performance. Treated feather mixes generally performed better, with the 1.25% concentration again demonstrating excellent sorptivity, suggesting sustained benefits over time. By the 90-day mark, the patterns remained consistent. The control mix and the 1.25% treated feather mix consistently showed excellent sorptivity, emphasizing their potential for long-term durability enhancement. Conversely, the 1% untreated feather mix continued to perform poorly, reinforcing concerns about using untreated feathers in concrete mixes.

In conclusion, the sorptivity test results highlighted that while untreated chicken feathers can detrimentally affect concrete properties, properly treated feathers can offer beneficial effects, particularly at higher concentrations (1.25%). These findings suggested a potential avenue for utilizing treated chicken feathers as sustainable additives in concrete mixes, provided they are processed effectively to mitigate water absorption. These observations align with literature on natural fibres in concrete, which generally report that untreated fibres increase sorptivity due to higher porosity and weaker fibre–matrix interfaces, while treated or optimized fibres can limit water ingress and improve durability indicators (Murthi et al., 2020).

4.6.3 Chloride conductivity results

The results shown in Table 4.9, offer insight into the performance of each mix over a 90-day period, highlighting the impact of chicken feathers on chloride conductivity.

Table 4.9: Chloride Conductivity Results for Concrete Mixes (28, 56, and 90 Days)

	Chloride Conductivity Results					
Mix Description	**28 Days**		**56 Days**		**90 Days**	
Mix 1- 0% CF	0.59	Excellent	0.67	Excellent	0.6	Excellent
Mix 2- 1% UCF	2.73	Very Poor	2.61	Very Poor	2.55	Very Poor
Mix 3 -1% TCF	1.26	Good	1.25	Good	0.89	Good
Mix 4- 0.75% TCF	1.3	Good	1.27	Good	0.82	Good
Mix 5 -1.25% TCF	0.72	Excellent	0.76	Excellent	0.62	Excellent

4.6.3.1 Chloride conductivity results (28 Days)

The results revealed significant differences in performance. Mix 1- 0% CF, demonstrated excellent chloride conductivity resistance (0.59), highlighting the effectiveness of the base concrete mix in preventing chloride ingress. In contrast, Mix 2- 1% UCF, showed a very poor result (2.73), emphasizing the detrimental effect of untreated additives on concrete's performance. Mix 3- 1% TCF and Mix 4- 0.75% TCF, exhibited good results (1.26 and 1.3, respectively), indicating that treated feathers improved resistance to chloride penetration compared to the untreated mix. The best performance was observed in Mix 5- 1.25% TCF, which achieved an excellent chloride conductivity value (0.72), suggesting that higher percentages of treated feathers further enhance the concrete’s resistance to chloride ingress. The findings demonstrated the potential of treated chicken feathers as a viable additive to improve concrete's durability, particularly in reducing chloride ion permeability.

4.6.3.2 Chloride conductivity results (56 Days)

Mix 1- 0% CF, demonstrated excellent chloride conductivity (0.67), indicating strong resistance to chloride ion penetration. In contrast, Mix 2- 1% UCF, showed a significant increase in chloride conductivity (2.61), classified as very poor. This result highlights the detrimental effect of untreated additives on concrete performance, accelerating chloride permeability and compromising the material's durability.

Mix 3- 1% TCF and Mix 4- 0.75% TCF, exhibited good chloride conductivity values (1.25 and 1.27), indicating that treated feathers reduce chloride ion penetration compared to untreated feathers, though not to the extent of the control mix. Finally, Mix 5- 1.25% TCF, demonstrated an excellent chloride conductivity value (0.76), suggesting that higher percentages of treated chicken feathers further enhance concrete's resistance to chloride ingress, improving its long-term durability.

Treated feathers were found to significantly reduce chloride conductivity and enhance concrete's resistance to corrosion, contributing to improved long-term durability compared to untreated feathers. These results suggest that treated chicken feathers hold promise as a sustainable fiber reinforcement to improve the performance of concrete in chloride-rich environments.

4.6.3.3 Chloride conductivity results (90 Days)

Mix 1- 0% CF, demonstrated excellent chloride conductivity (0.6), indicating strong resistance to chloride ion penetration and high durability. In contrast, Mix 2- 1% UCF showed a significantly higher chloride conductivity value (2.55), categorizing it as very poor, which highlights the negative impact of untreated feathers on concrete performance. Mix 3- 1% TC and Mix 4- 0.75% TCF, exhibited good chloride conductivity values (0.89 and 0.82, respectively), demonstrating that treated feathers enhanced resistance to chloride penetration, though slightly less effectively than the control mix. Mix 5- 1.25% TCF, recorded the best performance with an excellent chloride conductivity value of 0.62, suggesting that higher percentages of treated feathers offer superior protection against chloride ingress. The study concluded that treated chicken feathers improve concrete's ability to resist chloride-induced corrosion, enhancing its long-term durability compared to untreated feathers. These findings emphasized the importance of proper treatment of additives to optimize concrete performance. Further research is recommended to explore treatment methods, additive percentages, and environmental influences to maximize sustainability and extend infrastructure lifespan.

4.6.3.4 Chloride conductivity (28,56 and 90 Days)

Based on the chloride conductivity test results for the concrete mixes at 28, 56, and 90 days, several insights can be drawn regarding the influence of untreated and treated chicken feathers as additives. At 28 days, the control mix without feathers consistently demonstrated excellent chloride conductivity, indicating minimal permeability to chloride ions, which is crucial for concrete durability in aggressive environments. In contrast, the mix containing 1% untreated chicken feathers exhibited very poor conductivity, suggesting increased vulnerability to chloride penetration. This highlighted a potential drawback of using untreated feathers in concrete, likely due to their organic nature contributing to higher permeability. When feathers were treated, the results showed improvement. The mixes with 1% treated feathers and 0.75% treated feathers both displayed good chloride conductivity, comparable to the control mix. Notably, the mix with 1.25% treated feathers even showed excellent conductivity, suggesting a potential benefit of enhanced chloride resistance with higher feather concentrations. Moving to the 56-day results, similar trends were observed. The control mix maintained excellent chloride conductivity, while the mix with 1% untreated feathers continued to exhibit very poor performance. Treated feather mixes generally performed well, with variations across concentrations but consistently demonstrating good to excellent chloride resistance. By the 90-day mark, the patterns remained consistent with the earlier findings. The control mix and the mix with 1.25% treated feathers consistently showed excellent chloride conductivity, indicating sustained resistance to chloride penetration over time. In contrast, the mix with 1% untreated feathers continued to perform poorly, underscoring the persistent risk associated with untreated organic additives in concrete.

In conclusion, the chloride conductivity test results suggested that while untreated chicken feathers can increase chloride permeability and potentially compromise concrete durability, properly treated feathers can mitigate these effects. Specifically, higher concentrations of treated feathers (1.25%) showed promising results in enhancing chloride resistance, comparable to or even better than the control mix. This underscored the importance of proper treatment and concentration when considering chicken feathers as sustainable additives in concrete mixes. Further research could explore optimized treatment methods and their long-term effects on concrete performance, aiming to maximize the benefits of feather incorporation while minimizing any detrimental impacts.

The study on chloride conductivity of fiber-reinforced concrete showed that plain concrete (Mix 1, 0% CF) maintained excellent chloride resistance across 28, 56, and 90 days (0.59–0.67), consistent with literature reporting that dense, unreinforced matrices limit chloride ingress (Mohamed & Hawat, 2016). In contrast, Mix 2 (1% UCF) performed very poorly (2.73–2.55), suggesting that uncoated fibers may introduce weak interfacial zones and increase local porosity, creating preferential pathways for chloride penetration, an effect similarly observed in previous studies on untreated fibers (Oktarina et al., 2020). Treated carbon fiber mixes (Mixes 3–5) exhibited good to excellent chloride resistance, with values declining over time (e.g., Mix 5: 0.72 → 0.62), reflecting effective crack-bridging, reduced microcrack connectivity, and densified fiber–matrix interfaces, which aligns with literature demonstrating that surface-treated natural fibers enhance durability by controlling microstructure and limiting chloride diffusion (Ayyadurai et al., 2024). The improved performance of TCF over UCF highlights the importance of fiber treatment, dispersion, and optimal volume fraction, while the slight decline in conductivity over 90 days suggests continued hydration and microstructural refinement. Overall, the results confirm that natural fibers can improve chloride resistance when properly treated and incorporated, but untreated fibers may compromise durability due to increased permeability.

4.7 Dry Shrinkage Test

The drying shrinkage results for the concrete mixes are presented in Table 4.10. The table provides a detailed comparison of the shrinkage measurements across three samples for each mix. The average shrinkage values are calculated, and the range of shrinkage for each mix is noted, along with an indication of whether the range is less than or equal to 20% of the average shrinkage. These results are essential for understanding the consistency and behavior of the concrete mixes under drying conditions.

Table 4.10: Drying shrinkage results for the concrete mixes.

Mix #	**Sample 1 Shrinkage**	**Sample 2 Shrinkage**	**Sample 3 Shrinkage**	**Average Shrinkage**	**Range**	**Range ≤ 20% of Average?**
Mix 1- 0% CF	0.0211	0.0201	0.0208	0.02067	0.0010	Yes
Mix 2- 1% UCF	0.0390	0.0360	0.0364	0.03713	0.0030	Yes
Mix 3- 1% TCF	0.0194	0.0168	0.0160	0.0174	0.0034	Yes
Mix 4- 0.75% TCF	0.0268	0.0241	0.0256	0.0255	0.0027	Yes
Mix 5- 1.25% TCF	0.0139	0.0138	0.0137	0.0138	0.0002	Yes

The findings revealed a clear trend in shrinkage values across the mixes, with variations attributed to the presence and treatment of the feathers. Mix 1- 0% CF exhibited moderate shrinkage (average 0.02067) and a narrow range (0.0010), indicating consistent behavior in the absence of chicken feathers. Mix 2- 1% UCF, demonstrated the highest shrinkage (average 0.03713) and a wider range (0.0030). This suggested that untreated feathers contributed to increased shrinkage, likely due to the lack of structural stabilization. Mix 3- 1% TCF, showed a lower average shrinkage (0.0174), indicating that the treatment process likely improves the material’s resistance to shrinkage by enhancing bonding and structural integrity. Mix 4- 0.75% TCF, exhibited a moderate shrinkage of 0.0255, suggesting that even a small proportion of treated feathers can positively affect shrinkage control, though not as significantly as Mix 3- 1% TCF. Mix 5- 1.25% TCF, demonstrated the lowest shrinkage (0.0138) and an extremely narrow range (0.0002), highlighting the stabilizing effect of a higher proportion of treated feathers. This mix showed exceptional consistency in shrinkage behavior.

The results of this study indicate that both the treatment and proportion of natural fibres significantly influenced drying shrinkage in cementitious mixes. In the case of coconut fibres, the control mix without fibres (Mix 1) exhibited an average shrinkage of 0.02067, representing baseline behavior. The addition of 1% untreated coconut fibre (UCF, Mix 2) increased shrinkage to 0.03713, suggesting poor shrinkage control, likely due to weak fibre–matrix bonding and differential moisture absorption. Conversely, treated coconut fibres (TCF) demonstrated improved shrinkage performance: 1% TCF (Mix 3) reduced shrinkage to 0.0174, 0.75% TCF (Mix 4) recorded 0.0255, and 1.25% TCF (Mix 5) achieved the lowest shrinkage of 0.0138, indicating more stable and consistent behavior with higher fibre content. These observations align with literature reporting that fibres—natural or synthetic—act as crack-bridging elements that redistribute tensile stresses, mitigate capillary-driven shrinkage, and enhance deformation performance (Afroughsabet et al., 2018). The superior performance of treated fibres highlights the importance of fibre treatment, orientation, and effective bonding in controlling shrinkage, while untreated fibres may introduce microstructural weaknesses. Overall, the findings demonstrate that appropriately processed natural fibres, including coconut and chicken feathers, can significantly reduce drying shrinkage in cementitious composites, consistent with studies suggesting that organic fibres modify internal moisture dynamics to limit shrinkage (Kim et al., (2021).

4.7.1 Statistical Analysis for Dry Shrinkage Test results

The following analysis presents the statistical comparison of dry shrinkage across different mixes, as shown in Table 4.11. The table provides the p-values for each mix comparison, indicating whether the differences in dry shrinkage are statistically significant.

Table 4.11: Statistical Analysis of Dry shrinkage Comparison Across Different Mixes.

Mix Comparison	p-value	Significance Status
Mix 1- 0% CF vs Mix 2- 1% UCF	0.0016	Significant
Mix 1- 0% CF vs Mix 3- 1% TCF	0.0763	Not Significant
Mix 1- 0% CF vs Mix 4- 0.75% TCF	0.0156	Significant
Mix 1- 0% CF vs Mix 5- 1.25% TCF	0.0013	Significant

The analysis revealed several key findings. First, the addition of 1% untreated chicken feathers resulted in a statistically significant increase in shrinkage (p-value = 0.0016), indicating that untreated feathers exacerbate shrinkage. However, when the feathers were treated, the effect was mitigated. The mix with 1% treated chicken feathers showed no statistically significant difference from the control (p-value = 0.0763), suggesting that treatment effectively reduced shrinkage at this concentration. Conversely, the mix with 0.75% treated chicken feathers exhibited a significant increase in shrinkage (p-value = 0.0156), indicating that even lower percentages of treated feathers can still influence shrinkage. The 1.25% treated chicken feather mix showed a significant increase in shrinkage (p-value = 0.0013), reinforcing the finding that higher concentrations of treated feathers amplified the shrinkage effect. The study demonstrated that untreated chicken feathers significantly increased shrinkage in concrete, while treated feathers offer some reduction in shrinkage, particularly at lower concentrations.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This study investigated the impact of treated and untreated chicken feathers on the properties of concrete, focusing on workability, density, durability, compressive strength, tensile strength, and drying shrinkage. The findings revealed that treated chicken feathers enhanced workability, reduce drying shrinkage, and slightly improve durability, while slightly lowering compressive and tensile strength. Untreated chicken feathers, however, contributed to higher shrinkage and negatively impacted concrete strength. These results suggested that while treated chicken feathers is promising as a sustainable material for concrete, further optimization of their use is needed to balance workability and strength.

The following sub-sections presents the summary of findings for the undertaken study and are presented as follows:

5.1 Slump

This study explored the impact of untreated and treated chicken feather fibers on the workability of concrete, as measured by slump tests. The results showed that both the control mix and the mix with 1% untreated feathers exhibited a slump of 55 mm, indicating minimal impact on workability. In contrast, the mix with 1% treated feathers showed a reduced slump of 45 mm, suggesting that treatment improved the binding properties, leading to increased stiffness.

The highest workability was observed with 0.75% treated feathers, which resulted in a 60 mm slump. This indicated that this ratio struck an optimal balance between reinforcement and ease of handling. On the other hand, increasing the feather content to 1.25% treated feathers caused a further reduction in slump to 40 mm, demonstrating that higher fiber content can negatively impact workability.

The water absorption test results revealed that incorporating treated chicken feathers into concrete positively influenced moisture retention and overall durability. The control mix exhibited standard water absorption behavior, decreasing gradually over time as curing progressed. In contrast, the mix with 1% untreated chicken feathers showed higher water absorption, indicating increased porosity and potential long-term durability concerns. Mixes containing treated feathers (at 0.75% and 1%) displayed lower water absorption compared to the untreated mix, suggesting improved impermeability and better moisture control during curing. The 0.75% to 1% treated feather content offered the best balance, minimizing water absorption while maintaining structural integrity.

5.2 Compressive strength

The study demonstrated that the use of treated chicken feathers significantly improved the compressive strength of concrete, while untreated feathers had a detrimental effect. Mix 1- 0% CF, exhibited the highest compressive strength, confirming that concrete performs optimally without the inclusion of untreated organic materials. Mix 2- 1% UCF, showed the lowest strength due to the decay of the feathers, which interfered with the hydration process. In comparison to other mixes, Mix 3- 1% TCF, demonstrated the highest strength. This improvement is likely due to the treatment process, which helped prevent feather decay and allowed for better bonding between the feathers and the cement matrix. On the other hand, Mix 4- 0.75% TCF, showed slightly lower strength than Mix 3- 1% TCF. This suggests that 1% may be the optimal concentration of treated feathers for achieving maximum strength in concrete. Mix 5- 1.25% TCF had similar performance to Mix 3- 1% TCF, indicating that while higher concentrations of treated feathers could further enhance strength, this must be balanced carefully.

5.3 Tensile strength Conclusion

This study found that incorporating treated chicken feathers into concrete mixes enhanced tensile strength, with the most effective result observed in Mix 3- 1% TCF, which achieved a tensile strength of 7.09 MPa at 90 days. In contrast, Mix 2- 1% UCF, recorded the lowest tensile strength of 4.75 MPa. Statistical analysis confirmed that both untreated feathers and higher feather concentrations significantly deviated from the baseline mix. Notably, Mix 4- 0.75% TCF, demonstrated comparable strength performance over time, suggesting that the concentration of treated feathers plays a critical role in tensile strength outcomes.

5.4 Oxygen permeability

The results showed that treated chicken feathers improve concrete performance, especially at 1.25%. Untreated feathers produced invalid results, highlighting the need for proper treatment. The base mix performed well, but the addition of treated feathers enhanced strength and durability, particularly in oxygen permeability.

5.5 Sorptivity

The sorptivity tests showed that untreated chicken feathers increase water absorption, with the 1% untreated mix performing very poorly. Treated feathers, especially at 1.25%, improved water resistance and matched the control mix's performance. Lower treated percentages (0.75% and 1%) also showed good results.

5.6 Chloride resistance

The results showed that concrete with treated chicken feathers performed better than untreated feathers in resisting chloride penetration. The control mix (no feathers) demonstrated strong chloride resistance. Concrete with 1% untreated chicken feathers had poor performance, while treated feathers improved resistance, with the best results seen at 1.25% treated feathers.

5.7 Drying shrinkage

The test results showed that untreated chicken feathers increase drying shrinkage, while treated chicken feathers reduce shrinkage, especially at higher concentrations. Mix 5-1.25% TCF, exhibited the lowest and most consistent shrinkage, suggesting that treated feathers helped to stabilize the concrete mix.

5.8 Summary of Recommendations

Based on these findings, the following recommendations are made:

- Incorporation of Treated Chicken Feathers (TCF): Use treated chicken feathers at a dosage of 0.75% to 1.25% by weight of cement to enhance concrete properties. This range has been shown to improve tensile and compressive strength, durability, moisture retention, and resistance to chloride penetration, making it suitable for structural and exposure-prone applications.

- Avoidance of Untreated Chicken Feathers (UCF): Untreated feathers should be avoided in concrete mixes, as they increase porosity, weaken mechanical performance, interfere with hydration processes, and reduce durability and water resistance.
- Optimization of Treatment Methods: Refine feather treatment processes to ensure consistent performance, improve bonding with cement matrices, enhance long-term durability, and maximize sustainability and cost-effectiveness. Treatments could include chemical modification, surface coatings, or mechanical conditioning to improve fibre–matrix interaction.
- Determination of Optimal Dosage and Application-Specific Guidelines: Further experimental research should be conducted to identify the optimal feather concentration for different types of concrete applications (e.g., structural, pavements, or precast elements) and to investigate whether higher feather contents could provide additional benefits without compromising workability or mechanical performance.
- Long-Term Durability Assessment: Perform extended studies under various environmental conditions, such as freeze-thaw cycles, wet-dry variations, and chloride-rich exposures, to evaluate the long-term performance and resilience of concrete incorporating treated feathers.
- Commercial Scalability and Economic Feasibility: Investigate the potential for industrial-scale application of treated chicken feathers, including cost analysis, supply chain considerations, and consistency in performance, to ensure feasibility for widespread adoption in the concrete industry.

5.9 Concluding remarks

The tests on concrete mixes with varying percentages of treated and untreated chicken feathers revealed mixed results. While treated chicken feathers improved workability, reduced drying shrinkage, and enhanced durability, they slightly decreased the concrete's compressive and tensile strength compared to the control mix. Untreated chicken feathers, however, contributed to higher shrinkage and negatively impacted the strength of the concrete. Overall, treated chicken feathers showed potential for improving shrinkage control and workability, but their inclusion needs to be carefully balanced, as they may reduce the material's overall strength. Further research is recommended to optimize the treatment process and explore other additives to enhance concrete properties.

REFERENCES

ABDELSAMIE, K., AGWA, I. S., TAYEH, B. A. & HAFEZ, R. D. A. 2021. Improving the brittle behaviour of high-strength concrete using keratin and glass fibres. *Adv. Concr. Constr,* 12**,** 469-477.

ABOUSNINA, R., PREMASIRI, S., ANISE, V., LOKUGE, W., VIMONSATIT, V., FERDOUS, W. & ALAJARMEH, O. 2021. Mechanical properties of macro polypropylene fibre-reinforced concrete. *Polymers,* 13**,** 4112.

ABRAR, M., 2021. Workability of banana fibers reinforced concrete for easy pouring. In Proceedings of the 3rd conference on sustainability in civil engineering (5-9).

ACI Committee 544. (1996). State-of-the-art report on fiber reinforced concrete (ACI 544.1R-96). American Concrete Institute.

AFROUGHSABET, V., Biolzi, L., & Monteiro, P. J. (2018). The effect of steel and polypropylene fibers on the chloride diffusivity and drying shrinkage of high-strength concrete. Composites Part B: Engineering, 139, 84-96. https://doi.org/10.1016/j.compositesb.2017.11.047

AHMAD, J. & ZHOU, Z. 2022. Mechanical properties of natural as well as synthetic fiber reinforced concrete: a review. *Construction and Building Materials,* 333**,** 127353.

AL-MAHARMA, A. Y. & AL-HUNITI, N. 2019. Critical review of the parameters affecting the effectiveness of moisture absorption treatments used for natural composites. *Journal of Composites Science,* 3**,** 27.

ALEXANDER, M.G., MACKECHNIE, J.R., AND BALLIM, Y. (2001) Guide to the use of durability indexes for achieving durability in concrete structures, Research Monograph No. 2, published by the Department of Civil Engineering, University of Cape Town in collaboration with University of the Witwatersrand, 5-25.

ALI, M. F., HOSSAIN, M. S., MOIN, T. S., AHMED, S. & CHOWDHURY, A. S. 2021. Utilization of waste chicken feather for the preparation of eco-friendly and sustainable composite. *Cleaner Engineering and Technology,* 4**,** 100190.

ALTALABANI, D., BZENI, D. K. & LINSEL, S. 2020. Mechanical properties and load deflection relationship of polypropylene fiber reinforced self-compacting lightweight concrete. *Construction and Building Materials,* 252**,** 119084.

ANAS, M., KHAN, M., BILAL, H., JADOON, S. & KHAN, M. N. 2022. Fiber reinforced concrete: a review. *Engineering Proceedings,* 22**,** 3.

ARANBERRI, I., MONTES, S., WESOŁOWSKA, E., REKONDO, A., WRZEŚNIEWSKA-TOSIK, K. & GRANDE, H.-J. 2019. Improved thermal insulating properties of renewable polyol based polyurethane foams reinforced with chicken feathers. *Polymers,* 11**,** 2002.

ARAYA-LETELIER, G., GONZALEZ-CALDERON, H., KUNZE, S., BURBANO-GARCIA, C., REIDEL, U., SANDOVAL, C. & BAS, F. 2020. Waste-based natural fiber reinforcement of adobe mixtures: Physical, mechanical, damage and durability performance assessment. *Journal of cleaner production,* 273**,** 122806.

ARTAYANI, M., KUSNO, A., JAMALA, N. & MULYADI, R. 2024. Type on the Sound Absorption Coefficient Chicken Feather Composite. *ASTONJADRO,* 13**,** 477-483.

ATMAKURI, A., PALEVICIUS, A., VILKAUSKAS, A. & JANUSAS, G. 2020. Review of hybrid fiber based composites with nano particles—material properties and applications. *Polymers,* 12**,** 2088.

AYYADURAI, A., Maruthai, S. M., & Muthu, D. (2024). Impact of fly ash and banana fiber on mechanical performance of paver block concrete. Journal of the Croatian Association of Civil Engineers, 76(03), 211-222. https://doi.org/10.14256/jce.3873.2023

BARCUS, M., MIZRACHI, D. & LEI, X. G. 2017. Identification and kinetics characterization of a wax ester hydrolase from a feather-degrading actinomycete. *BioRxiv***,** 178673.

BHEEL, N., TAFSIROJJAMAN, T., LIU, Y., AWOYERA, P., KUMAR, A. & KEERIO, M. A. 2021. Experimental study on engineering properties of cement concrete reinforced with nylon and jute fibers. *Buildings,* 11**,** 454.

BUI, H., SEBAIBI, N., BOUTOUIL, M. & LEVACHER, D. 2020. Determination and review of physical and mechanical properties of raw and treated coconut fibers for their recycling in construction materials. *Fibers,* 8**,** 37.

CHEN, S., HORI, N., KAJIYAMA, M. & TAKEMURA, A. 2020. Compatibilities and properties of poly lactide/poly (methyl acrylate) grafted chicken feather composite: Effects of graft chain length. *Journal of Applied Polymer Science,* 137**,** 48981.

CHEN, Y., Yu, Q., & Brouwers, H. (2017). Acoustic performance and microstructural analysis of bio-based lightweight concrete containing miscanthus. Construction and Building Materials, 157, 839-851. https://doi.org/10.1016/j.conbuildmat.2017.09.161

DE AZEVEDO, A. R., MARVILA, M. T., ANTUNES, M. L. P., RANGEL, E. C. & FEDIUK, R. 2021. Technological perspective for use the natural pineapple fiber in mortar to repair structures. *Waste and Biomass Valorization,* 12**,** 5131-5145.

DEACONU, O. & CHIŢONU, G. 2022 Using fibers in construction. IOP Conference Series: Materials Science and Engineering, 2022. IOP Publishing, 012013.

DINU, R., CANTARUTTI, C. & MIJA, A. 2020. Design of sustainable materials by cross-linking a biobased epoxide with keratin and lignin. *ACS sustainable chemistry & engineering,* 8**,** 6844-6852.

DVORKIN, L., BORDIUZHENKO, O., TEKLE, B. H. & RIBAKOV, Y. 2021. A method for the design of concrete with combined steel and basalt fiber. *Applied Sciences,* 11**,** 8850.

NJOKU, C.E, ALANEME, K., OMOTOYINBO, J. A & DARAMOLA, M.O 2019. Natural fibers as viable sources for the development of structural, semi-structural, and technological materials–a review. *Advanced Materials Letters,* 10**,** 682-694.

EJIGU, T. and Gebre, A. (2023). Effect of fiber treatments on the mechanical properties of sisal fiber-reinforced concrete composites. Advances in Civil Engineering, 2023, 1-15. https://doi.org/10.1155/2023/2293857

EL-KHORDAGUI, L., BADAWEY, S. E. & HEIKAL, L. A. 2021. Application of biosurfactants in the production of personal care products, and household detergents and industrial and institutional cleaners. *Green Sustainable Process for Chemical and Environmental Engineering and Science.* Elsevier.

GAGG, C. R. 2014. Cement and concrete as an engineering material: An historic appraisal and case study analysis. *Engineering Failure Analysis,* 40**,** 114-140.

GARG, M., AZARSA, P. & GUPTA, R. 2021. Self-healing potential and post-cracking tensile behavior of polypropylene fiber-reinforced cementitious composites. *Journal of Composites Science,* 5**,** 122.

GUERINI, V., CONFORTI, A., PLIZZARI, G. & KAWASHIMA, S. 2018. Influence of steel and macro-synthetic fibers on concrete properties. *Fibers,* 6**,** 47.

GUO, H., TAO, J., CHEN, Y., LI, D., JIA, B. & ZHAI, Y. 2019. Effect of steel and polypropylene fibers on the quasi-static and dynamic splitting tensile properties of high-strength concrete. *Construction and Building Materials,* 224**,** 504-514.

HU, B., ZHANG, N., LIAO, Y., PAN, Z., LIU, Y., ZHOU, L., LIU, Z. & JIANG, Z. 2018. Enhanced flexural performance of epoxy polymer concrete with short natural fibers. *Science China Technological Sciences,* 61**,** 1107-1113.

INIYA, M. & NIRMALKUMAR, K. A Review on Fiber Reinforced Concrete using sisal fiber. IOP Conference Series: Materials Science and Engineering, 2021. IOP Publishing, 012027.

JALAL, A., HAKIM, L. & SHAFIQ, N. 2021. Mechanical and post-cracking characteristics of fiber Reinforced concrete containing copper-coated steel and PVA fibers in 100% cement and fly ash concrete. *Applied Sciences,* 11**,** 1048.

JAMSHAID, H., MISHRA, R. K., RAZA, A., HUSSAIN, U., RAHMAN, M. L., NAZARI, S., CHANDAN, V., MULLER, M. & CHOTEBORSKY, R. 2022. Natural cellulosic fiber reinforced concrete: influence of fiber type and loading percentage on mechanical and water absorption performance. *Materials,* 15**,** 874.

KELLE, H. & EBOATU, A. 2018. Determination of the viability of chicken feather as oil spill clean-up sorbent for crude oil and its lower fractions. *Journal of Applied Sciences and Environmental Management,* 22**,** 267–273-267–273.

KIM, D. J., Kim, S., & Choi, W. (2021). Characteristics of restrained drying shrinkage on arched steel fiber-reinforced concrete. Applied Sciences, 11(16), 7537. https://doi.org/10.3390/app11167537

KOCAK, S., KORKMAZ, K. & BOZTAS, E. 2022. Impact of Polymer Coating on the Flexural Strength and Deflection Characteristics of Fiber-Reinforced Concrete Beams. *Journal of Building Material Science,* 4**,** 26-35.

KONIKI, S. & RAVI PRASAD, D. 2019. Mechanical properties and constitutive stress–strain behaviour of steel fiber reinforced concrete under uni-axial stresses. *Journal of Building Pathology and Rehabilitation,* 4**,** 1-8.

KRUSCHWITZ, S., OESCH, T., MIELENTZ, F., MEINEL, D. & SPYRIDIS, P. 2022. Non-Destructive Multi-Method Assessment of Steel Fiber Orientation in Concrete. *Applied Sciences,* 12**,** 697.

KRZYWIŃSKI, K., SADOWSKI, Ł., STEFANIUK, D., OBROSOV, A. & WEIß, S. 2022. Engineering and manufacturing technology of green epoxy resin coatings modified with recycled fine aggregates. *International Journal of Precision Engineering and Manufacturing-Green Technology,* 9**,** 253-271.

KURIEN, R. A., BIJU, A., RAJ, K. A., CHACKO, A., JOSEPH, B. & KOSHY, C. P. 2022. Chicken feather fiber reinforced composites for sustainable applications. *Materials Today: Proceedings,* 58**,** 862-866.

KURNIANINGSIH, O., PRADANA, H. C. G., RAHMI, A. T., PRATIWI, K. H. & LEGOWO, S. J. 2023. Utilization of plastic bottles and fiber mask in eco-friendly concrete mixtures. IOP Conference Series: Earth and Environmental Science, 2023. IOP Publishing, 012017.

KUSUMAWARDANI, R., KARNINGSIH, P. D., KURNIATI, N., SINGGIH, M. L., SUPRIYANTO, H., SUTIKNO, S., WARNANA, D. D. & SITANGGANG, I. M. 2023. Slaughterhouse Waste Treatment Equipment to Produce Plant Fertilizer and Fish Feed. *IPTEK Journal of Proceedings Series*, 1-7.

LILARGEM ROCHA, D., TAMBARA JÚNIOR, L. U. D., MARVILA, M. T., PEREIRA, E. C., SOUZA, D. & DE AZEVEDO, A. R. G. 2022. A review of the use of natural fibers in cement composites: concepts, applications and Brazilian history. *Polymers,* 14**,** 2043.

LIM, S. K., Tiong, H. Y., & Woon, K. S. (2018). Compressive strength and dimensional stability of palm oil empty fruit bunch fibre reinforced foamed concrete. E3S Web of Conferences, 65, 02001. https://doi.org/10.1051/e3sconf/20186502001

LOGANATHAN, M., DINESH, S., VIJAYAN, V., RANJITHKUMAR, M. & RAJKUMAR, S. 2020. Experimental investigation of tensile strength of fiber reinforced polyester by using chicken feather fiber. *Journal of New Materials for Electrochemical Systems,* 23**,** 40-44.

LUMINGKEWAS, R. H., Husen, A., & Andrianus, R. (2017). Effect of fibers length and fibers content on the splitting tensile strength of coconut fibers reinforced concrete composites. Key Engineering Materials, 748, 311-315. https://doi.org/10.4028/www.scientific.net/kem.748.311

LUO, Y., Niu, D., & Su, L. (2021). Chloride diffusion property of hybrid basalt–polypropylene fibre-reinforced concrete in a chloride–sulphate composite environment under drying–wetting cycles. Materials, 14(5), 1138. https://doi.org/10.3390/ma14051138

MAHMOOD, H., TRIPATHI, M., PUGNO, N. & PEGORETTI, A. 2016. Enhancement of interfacial adhesion in glass fiber/epoxy composites by electrophoretic deposition of graphene oxide on glass fibers. *Composites Science and Technology,* 126**,** 149-157.

MAILYAN, L. R., BESKOPYLNY, A. N., MESKHI, B., SHILOV, A. V., STEL'MAKH, S. A., SHCHERBAN', E. M., SMOLYANICHENKO, A. S. & EL'SHAEVA, D. 2021. Improving the structural characteristics of heavy concrete by combined disperse reinforcement. *Applied Sciences,* 11**,** 6031.

MAKUL, N. 2020. Advanced smart concrete-A review of current progress, benefits and challenges. *Journal of Cleaner Production,* 274**,** 122899.

MARINKOVIĆ, S., CAREVIĆ, V. & DRAGAŠ, J. 2021. The role of service life in Life Cycle Assessment of concrete structures. *Journal of cleaner production,* 290**,** 125610.

MENNA, C., MATA-FALCÓN, J., BOS, F. P., VANTYGHEM, G., FERRARA, L., ASPRONE, D., SALET, T. & KAUFMANN, W. 2020. Opportunities and challenges for structural engineering of digitally fabricated concrete. *Cement and Concrete Research,* 133**,** 106079.

MIZANI, J., SADEGHI, A. M. & AFSHIN, H. 2022. Experimental study on the effect of macro and microfibers on the mechanical properties of reactive powder concrete. *Structural Concrete,* 23**,** 240-254.

MOCHANE, M., MOKHENA, T. C., MOKHOTHU, T., MTIBE, A., SADIKU, E., RAY, S. S., IBRAHIM, I. & DARAMOLA, O. 2019. Recent progress on natural fiber hybrid composites for advanced applications: A review.

MOHAMED, O. A. and Hawat, W. A. (2016). Influence of fly ash and basalt fibers on strength and chloride penetration resistance of self-consolidating concrete. Materials Science Forum, 866, 3-8. https://doi.org/10.4028/www.scientific.net/msf.866.3

Momoh, E. O., Osofero, A. I., & Menshykov, O. (2022). Bond behaviour of treated natural fibre in concrete. Nano Hybrids and Composites, 34, 37-44. https://doi.org/10.4028/p-h40o32

MOUTHANNA, A. 2022. Effect of Natural Fibers from Palm Fronds on The Mechanical Properties of Concrete. *Anbar Journal of Engineering Sciences,* 13**,** 69-73.

MRAJJI, O., EL WAZNA, M., EL BOUARI, A. & CHERKAOUI, O. 2022. The properties of feather fiber-reinforced polymer composites: a review. *Journal of Natural Fibers,* 19**,** 4868-4885.

MURTHI, P., Poongodi, K., Gobinath, R., & Saravanan, R. (2020). Evaluation of material performance of coir fibre reinforced quaternary blended concrete. IOP Conference Series: Materials Science and Engineering, 872(1), 012133. https://doi.org/10.1088/1757-899x/872/1/012133

NIE, R., HUANG, Y., LI, X., SUN, H., LI, D. & YING, J. 2020. Bond of epoxy-coated reinforcement to seawater coral aggregate concrete. *Ocean Engineering,* 208**,** 107350.

OKEOLA, A. A., ABUODHA, S. O. & MWERO, J. 2018. Experimental investigation of the physical and mechanical properties of sisal fiber-reinforced concrete. *Fibers,* 6**,** 53.

OKTARINA, D., Fadilasari, D., & Juansyah, Y. (2020). Comparative analysis the addition of natural and artificial fibres in concrete. IOP Conference Series: Materials Science and Engineering, 807(1), 012002. https://doi.org/10.1088/1757-899x/807/1/012002

OLUBA, O. M., OBI, C. F., AKPOR, O. B., OJEABURU, S. I., OGUNROTIMI, F. D., ADEDIRAN, A. A. & OKI, M. 2021. Fabrication and characterization of keratin starch biocomposite film from chicken feather waste and ginger starch. *Scientific Reports,* 11**,** 8768.

ONUAGULUCHI, O. and Banthia, N., 2016. Plant-based natural fibre reinforced cement composites: A review. Cement and Concrete Composites, 68, 96-108.

OUAKARROUCH, M., LAAROUSSI, N. & GAROUM, M. 2020. Thermal characterization of a new bio-composite building material based on plaster and waste chicken feathers. *Renewable Energy and Environmental Sustainability,* 5**,** 2.

OWEN, M. M., ACHUKWU, E. O., AKIL, H. M., ROMLI, A. Z., ZAINOL ABIDIN, M. S., ARUKALAM, I. O. & ISHIAKU, U. S. 2022. Effect of epoxy concentrations on thermo-mechanical properties of kenaf fiber–recycled poly (ethylene terephthalate) composites. *Journal of Industrial Textiles,* 52**,** 15280837221127441.

OWEN, M. M., ACHUKWU, E. O., SHUIB, S. B., AHMAD, Z. R., ABDULLAH, A. H. & ISHIAKU, U. S. 2023. Effects of high-temperature optimization and resin coating treatment on the mechanical, thermal, and morphological properties of natural kenaf fiber-filled engineering plastic composites. *Polymer Composites,* 44**,** 2512-2529.

OYEBISI, S., OLUTOGE, F., OYAOTUDEREKUMOR, I., BANKOLE, F., OWAMAH, H. & MAZINO, U. 2022. Effects of cashew nutshell ash on the thermal and sustainability properties of cement concrete. *Heliyon,* 8.

PACHECO-TORGAL, F., GONZALEZ, J. & JALALI, S. 2012. Sustainable monitoring of concrete structures: strength and durability performance of polymer-modified self-sensing concrete. *International Journal of Sustainable Engineering,* 5**,** 170-174.

PAŞAYEV, N., ARABACILAR, Z. & ÇADIR, M. 2022. Cleaning method of chicken feathers to obtain odorless fibers. *Journal of Natural Fibers,* 19**,** 14666-14677.

PAŞAYEV, N., KOCATEPE, S., MARAŞ, N., SOYLAK, M. & EROL, M. 2017 Investigation some characteristics of chicken feather's rachis. IOP Conference Series: Materials Science and Engineering, 2017. IOP Publishing, 192013.

PAVITHRA, C., AROKIAPRAKASH, A. & MAHESHWARI, A. 2021. Behaviour of concrete adding chicken feather as fibre with partial replacement of cement with Cashewnut shell powder. *Materials Today: Proceedings,* 43**,** 1173-1178.

RAO, C. S., SABITHA, R., MURUGAN, P., RAO, S. R., ANITHA, K. & RAO, Y. S. 2021. A novel study of synthesis and experimental investigation on hybrid biocomposites for biomedical orthopedic application. *International Journal of Polymer Science,* 2021**,** 7549048.

REDDY, N. & YANG, Y. 2010. Light-weight polypropylene composites reinforced with whole chicken feathers. *Journal of applied polymer science,* 116**,** 3668-3675.

RUMBAYAN, R., SUDARNO, S. & TICOALU, A. 2019. Plagiarism Checker: A Study Into Flexural, Compressive and Tensile Strength of Coir-Concrete as Sustainable Building Material. MATEC Web of Conferences, 2019. EDP Sciences.

SÁNCHEZ, M., FARIA, P., FERRARA, L., HORSZCZARUK, E., JONKERS, H., KWIECIEŃ, A., MOSA, J., PELED, A., PEREIRA, A. & SNOECK, D. 2018. External treatments for the preventive repair of existing constructions: A review. *Construction and Building Materials,* 193**,** 435-452.

SHAH, I., Li, J., Yang, S., Zhang, Y., & Anwar, A. (2022). Experimental investigation on the mechanical properties of natural fiber reinforced concrete. Journal of Renewable Materials, 10(5), 1307-1320. https://doi.org/10.32604/jrm.2022.017513

SHAVANDI, A. & ALI, M. A. 2019. Keratin based thermoplastic biocomposites: a review. *Reviews in Environmental Science and Bio/Technology,* 18**,** 299-316.

SŁOWIK, M. & AKRAM, A. 2021. Length effect at testing splitting tensile strength of concrete. *Materials,* 15**,** 250.

SUTARNO, S., RAHMAWATI, D. & MASVIKA, H. 2021. Effect of chicken feather waste on concrete mixing on compressive strength and flexural strength. *ASTONJADRO,* 10**,** 162-172.

SANS 50197-1:2014: Cement – Part 1: Composition, specifications and conformity criteria for common cements. Approved 1 October 2014. Pretoria: SABS Standards Division.

SANS 50196-2:2006: Methods of testing cement – Part 2: Chemical analysis of cement. Approved 2006. Pretoria: SABS Standards Division.

SANS 2001-1:2007/EN 1008: Construction works – Part CC1: Concrete works (structural); EN 1008: Mixing water for concrete – Specifications for sampling, testing and assessing suitability of water as mixing water. Approved and published April 2007. Pretoria: SABS Standards Division.

SANS 10100:2000: The structural use of concrete – Part 1: Design. Approved 13 August 1992; Amendment No. 2 approved 31 March 2000. Pretoria: SABS Standards Division

SANS 3001-CO2-7: Civil engineering test methods – Part CO2-7: Initial drying shrinkage and wetting expansion of concrete. Approved 30 June 2019. Pretoria: SABS Standards Division.

SANS 5861-1:2006: Concrete tests – Part 1: Mixing fresh concrete in the laboratory. Approved 22 September 2006. Pretoria: SABS Standards Division.

SANS 5861-2:2006: Concrete testing – Sampling of freshly mixed concrete. Approved 22 September 2006. Pretoria: SABS Standards Division.

SANS 5861-3:2006: Concrete testing – Making and curing of test specimens. Approved 22 September 2006. Pretoria: SABS Standards Division.

SANS 5838:2006: Sand equivalent value of fine aggregates. Approved 22 September 2006. Pretoria: SABS Standards Division.

SANS 201:2008: Sieve analysis, fines content and dust content of aggregates. Approved 15 February 2008. Pretoria: SABS Standards Division.

SANS 5862-1:2006: Concrete tests – Consistence of freshly mixed concrete – Slump test. Approved 6 October 2006. Pretoria: SABS Standards Division.

SANS 5863:2006: Concrete tests – Compressive strength of hardened concrete. Approved 22 September 2006. Pretoria: SABS Standards Division.

SANS 6253:2006: Concrete tests – Tensile splitting strength of concrete. Approved 17 November 2006. Pretoria: SABS Standards Division.

SANS 3001-CO3-2: Civil engineering test methods – Part CO3-2: Concrete durability index testing – Oxygen permeability test. Approved 30 June 2015. Pretoria: SABS Standards Division.

SANS 3001-CO3-1: Civil engineering test methods – Part CO3-1: Concrete durability index testing – Preparation of test specimens. Approved 30 June 2015. Pretoria: SABS Standards Division.

SANS 3001-CO3-3: Civil engineering test methods – Part CO3-3: Concrete durability index testing – Chloride conductivity test. Approved 30 June 2015. Pretoria: SABS Standards Division.

TAGHIYARI, H. R., MILITZ, H., ANTOV, P. & PAPADOPOULOS, A. N. 2021. Effects of wollastonite on fire properties of particleboard made from wood and chicken feather fibers. *Coatings,* 11**,** 518.

TESFAYE, T., SITHOLE, B., RAMJUGERNATH, D. & NDLELA, L. 2018. Optimisation of surfactant decontamination and pre-treatment of waste chicken feathers by using response surface methodology. *Waste management,* 72**,** 371-388.

TORRES, J. A. & LANTSOGHT, E. O. 2019. Influence of fiber content on shear capacity of steel fiber-reinforced concrete beams. *Fibers,* 7**,** 102.

TOUMI, B. 2024. Thermomechanical Behaviour of Concrete Reinforced With Synthetic And Organic Fibers.

UNIVERSITY OF CAPE TOWN and University of the Witwatersrand, 2018. Durability index testing procedure manual. Version 5.0, 6 November 2023 [Accessed 4 December 2023]. Available online at: chrome extension://efaidnbmnnnibpcajpcglclefindmkaj/https://concretesocietysa.org.za/concrete-tools/UCT-WITS-DI-Manual_2023-Ver-5.0_2023-11-06.pdf

VALCUENDE, M., Lliso-Ferrando, J. R., Roig-Flores, M., & Gandía-Romero, J. M. (2021). Porous structure of ultra-high-performance fibre-reinforced concretes. Materials, 14(7), 1637. https://doi.org/10.3390/ma14071637

VERMA, A., NEGI, P. & SINGH, V. K. 2019. Experimental analysis on carbon residuum transformed epoxy resin: chicken feather fiber hybrid composite. *Polymer Composites,* 40**,** 2690-2699.

VERMA, S. K. & AHIRWAR, A. K. 2017. Coconut Coir & Polypropylene Reinforced Concrete. *International Journal of Engineering Research & Technology (IJERT),* 6**,** 2278-0181.

VIJAYALAKSHMI, R., Balamurugan, Y., Selvam, P., Kalimuthu, N., & Giri, T. (2023). Influence of biomass ash and coconut shell in scrap steel fiber reinforced concrete. Gradjevinski Materijali I Konstrukcije, 66(1), 25-41. https://doi.org/10.5937/grmk2301025r

WANG, W., SHEN, A., LYU, Z., HE, Z. & NGUYEN, K. T. 2021. Fresh and rheological characteristics of fiber reinforced concrete——A review. *Construction and Building Materials,* 296**,** 123734.

WANG, X., HE, J., MOSALLAM, A. S., LI, C. & XIN, H. 2019. The effects of fiber length and volume on material properties and crack resistance of basalt fiber reinforced concrete (BFRC). *Advances in Materials Science and Engineering,* 2019**,** 1-17.

WANG, Y., GAO, S. & LI, W. 2022. Study on compression deformation and damage characteristics of pine needle fiber-reinforced concrete using DIC. *Materials,* 15**,** 1654.

WEI, J. & MEYER, C. 2014. Degradation rate of natural fiber in cement composites exposed to various accelerated aging environment conditions. *Corrosion science,* 88**,** 118-132.

WINDISCH, A. 2021. The tensile strength: the most fundamental mechanical characteristics of concrete. *CONCRETE STRUCTURES: JOURNAL OF THE HUNGARIAN GROUP OF FIB,* 22**,** 1-4.

YAN, D.-M., CHEN, S.-K., CHEN, G.-D. & BAIRD, J. 2016. Static and dynamic behavior of concrete slabs reinforced with chemically reactive enamel-coated steel bars and fibers. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering),* 17**,** 366-377.

YOUNG, B. A., HALL, A., PILON, L., GUPTA, P. & SANT, G. 2019. Can the compressive strength of concrete be estimated from knowledge of the mixture proportions?: New insights from statistical analysis and machine learning methods. *Cement and concrete research,* 115**,** 379-388.

YUE, Y., BAI, Y., BASHEER, P. M., BOLAND, J. J. & WANG, J. J. 2013 Preliminary research on monitoring the durability of concrete subjected to sulfate attack with optical fibre Raman spectroscopy. Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2013, 2013. SPIE, 162-175.

YUE, Y., WANG, J. J., BASHEER, P. M., BOLAND, J. J. & BAI, Y. 2017. Characterisation of carbonated Portland cement paste with optical fibre excitation Raman spectroscopy. *Construction and Building Materials,* 135**,** 369-376.

ZAHRA, H., SELINGER, J., SAWADA, D., OGAWA, Y., ORELMA, H., MA, Y., KUMAGAI, S., YOSHIOKA, T. & HUMMEL, M. 2022. Evaluation of Keratin–Cellulose Blend

Fibers as Precursors for Carbon Fibers. *ACS Sustainable Chemistry & Engineering,* 10**,** 8314-8325.

ZHANG, T. & PAN, D. 2021. Mechanical properties of steel-polypropylene hybrid fiber reinforced concrete in building structure: steel-polypropylene hybrid fiber reinforced concrete in building structure. *Stavební obzor-Civil Engineering Journal,* 30.

ZHANG, W., ZHENG, Q., ASHOUR, A. & HAN, B. 2020. Self-healing cement concrete composites for resilient infrastructures: A review. *Composites Part B: Engineering,* 189**,** 107892.

ZHANG, X., YIN, R., CHEN, Y. & LOU, C. 2023. Experimental study on the axial tensile properties of polypropylene fiber reinforced concrete. *Scientific Reports,* 13**,** 16383.

ZHENG, Y., WU, X., HE, G., SHANG, Q., XU, J. & SUN, Y. 2018. Mechanical properties of steel fiber-reinforced concrete by vibratory mixing technology. *Advances in Civil Engineering,* 2018.

ANNEXURES

ANNEXURE A

A.1 Workability

Table A.1: Slump Results- Workability Analysis

Concrete Mix	Slump (mm)
Mix 1- 0% CF	55
Mix 2- 1% UCF	55
Mix 3- 1% TCF	45
Mix 4- 0.75% TCF	60
Mix 5- 1.25% TCF	40

A.2 Compressive Strength Results

Table A.2: Compressive Strength Results Mix 1- 0% CF

Mix 1- 0% CF					
#	Mass(g)	Force (KN)	Compressive Strength (MPa)		Average
1	2484.7	536.6	53.66	7 Days	56.44
2	2486.8	563.7	56.37		
3	2391.2	592.9	59.29		
1	2505	609.7	60.97	14 Days	59.49
2	2379	584.1	58.41		
3	2413	590.93	59.09		
1	2410.4	690.1	69.01	28 Days	68.68
2	2457.1	684.1	68.41		
3	2439.9	686.3	68.63		
1	2450.3	716.9	71.69	56 Days	70.11
2	2486.7	697.9	69.79		
3	2463.6	688.6	68.86		
1	2496.9	708.7	70.87	90 Days	72.13
2	2480.7	752.4	75.24		
3	2499.1	702.8	70.28		

Table A.3: Compressive Strength Results Mix 2- 1% UCF

Mix 2- 1% UCF					
#	**Mass(g)**	**Force(KN)**	**Compressive Strength (MPa)**		**Avarage**
1	2315.3	269.4	26.94	7 Days	26.82
2	2285.2	267.6	26.76		
3	2382.7	267.6	26.76		
1	2266	323.7	32.37	14 Days	31.51
2	2292	313	31.3		
3	2300	308.6	30.86		
1	2211.3	371.3	37.13	28 Days	37.2
2	2172.7	368.4	36.84		
3	2213.4	376.3	37.63		
1	2156.8	421.3	42.13	56 Days	42.89
2	2266.1	419.6	41.96		
3	2192.7	445.8	44.58		
1	2229.1	480.1	48.01	90 Days	48.58
2	2331.2	406.4	40.64		
3	2202.4	570.9	57.09		

Table A.4: Compressive Strength Results Mix Mix 3 - 1% TCF

Mix 3 - 1% TCF					
#	**Mass(g)**	**Force(KN)**	**Compressive Strength (MPa)**		**Avarage**
1	2434.3	533.5	53.35	7 Days	52.00
2	2399	507.4	50.74		
3	2414.7	519	51.9		
1	2382.5	573.5	57.35	14 Days	58.82
2	2369.3	586.2	58.62		
3	2349.8	604.96	60.496		
1	2449.9	680.3	68.03	28 Days	64.14
2	2390.4	581.61	58.161		
3	2343.1	662.2	66.22		
1	2457.5	649.97	64.97	56 Days	65.17
2	2501.4	638.8	63.88		
3	2392.7	666.46	66.65		
1	2434.1	699.9	69.99	90 Days	65.50
2	2335.1	655.6	65.56		
3	2408.2	609.59	60.959		

Table A.5: Compressive Strength Results Mix 4- 0.75% TCF

Mix 4 - 0.75% TCF					
#	**Mass(g)**	**Force(KN)**	**Compressive Strength (MPa)**		**Avarage**
1	2353.6	509.5	50.95	7 Days	51.06
2	2479.1	494.9	49.49		
3	2468.8	527.5	52.75		
1	2382.5	537.8	53.78	14 Days	54.11
2	2369.3	515.1	51.51		
3	2398.8	570.4	57.04		
1	2418.5	548.9	54.89	28 Days	56.00
2	2391.9	566.3	56.63		
3	2454.6	564.9	56.49		
1	2312.4	582.8	58.28	56 Days	58.91
2	2344.8	529.8	52.98		
3	2322.1	654.7	65.47		
1	2406.2	608.3	60.83	90 Days	64.39
2	2362.4	690.4	69.04		
3	2469.1	632.88	63.29		

Table A.6: Compressive Strength Results Mix E - 1.25% TCF

Mix 5 - 1.25% TCF					
#	**Mass(g)**	**Force(KN)**	**Compressive Strength (MPa)**		**Avarage**
1	2353.8	516.9	51.69	7 Days	52.17
2	2369	512.5	51.25		
3	2288.6	535.8	53.58		
1	2451.8	579.6	57.96	14 Days	57.81
2	2449.6	546.4	54.64		
3	2453.7	608.3	60.83		
1	2502.4	612.3	61.23	28 Days	63.38
2	2431.3	638.7	63.87		
3	2400	650.3	65.03		
1	2452.6	670.6	67.06	56 Days	66.46
2	2463.9	647.8	64.78		
3	2482.2	675.5	67.55		
1	2425.8	668.5	66.85	90 Days	67.22
2	2472.2	671.6	67.16		
3	2415.8	676.6	67.66		

A.3 Splitting Tensile Strength Results

Table A.6: Splitting Tensile Strength Results Mix 1-0% CF

Mix 1-0% CF					
#	**Mass(g)**	**Force(KN)**	**Tensile Strength (MPa)**		**Avarage**
1	2456.5	154.85	4.3816	7 Days	4.53
2	2474.4	160.33	4.5364		
3	2488.9	164.77	4.6618		
1	2462	259.69	7.3478	14 Days	6.72
2	2376	210.54	5.971		
3	2431	241.97	6.8465		
1	2454.5	214.42	6.067	28 Days	7.16
2	2471.6	276.78	7.8314		
3	2469.1	267.66	7.5734		
1	2489.1	279.94	7.9207	56 Days	7.91
2	2481.6	278.59	7.8824		
3	2492.7	280.59	7.9391		
1	2469	305.41	8.6413	90 Days	8.47
2	2392.6	293.51	8.3047		
3	2429.4	299.24	8.4668		

Table A.7: Splitting Tensile Strength Results Mix 2 - 1% UCF

Mix 2 - 1% UCF					
#	**Mass(g)**	**Force(KN)**	**Tensile Strength (MPa)**		**Avarage**
1	2091.3	90.24	2.5533	7 Days	2.57
2	2215.9	90.83	2.5701		
3	2182.4	91.57	2.5911		
1	2182.5	113.97	3.2249	14 Days	3.26
2	2195.1	116.14	3.2861		
3	2203.5	115.79	3.2762		
1	2248.3	134.67	3.8104	28 Days	3.83
2	2196.3	136.56	3.8639		
3	2233.7	134.99	3.8196		
1	2214.7	151.92	4.2986	56 Days	4.39
2	2230	154.6	4.3744		
3	2212.7	158.85	4.4946		
1	2204.1	166.48	4.7103	90 Days	4.75
2	2142.7	167.16	4.7298		
3	2126.7	169.69	4.8012		

Table A.8: Splitting Tensile Strength Results Mix 3 - 1% TCF

Mix 3 - 1% TCF					
#	**Mass(g)**	**Force(KN)**	**Tensile Strength (MPa)**		**Avarage**
1	2453.1	189.44	5.3602	7 Days	5.38
2	2346.2	191.83	5.4279		
3	2448.2	189.54	5.3629		
1	2434.6	206.24	5.8355	14 Days	5.83
2	2428.1	206.29	5.8369		
3	2458.8	206.05	5.8303		
1	2424	218.2	6.174	28 Days	6.41
2	2440.1	227.8	6.4455		
3	2402.4	234.01	6.6211		
1	2429.4	244.94	6.9305	56 Days	7.00
2	2467.9	223.98	6.3374		
3	2492.8	273.06	7.7262		
1	2375.2	257.63	7.2895	90 Days	7.09
2	2325.6	238.67	6.7532		
3	2434	255.61	7.2323		

Table A.9: Splitting Tensile Strength Results Mix 4 - 0.75% TCF

Mix 4 - 0.75% TCF					
#	**Mass(g)**	**Force(KN)**	**Tensile Strength (MPa)**		**Avarage**
1	2489.8	189.27	5.3533	7 Days	5.40
2	2375.1	187.38	5.3009		
3	2478.8	196.03	5.5408		
1	2372.8	185.59	5.2513	14 Days	5.44
2	2370.9	176.55	4.9955		
3	2379.6	215.08	6.0857		
1	2402	196.68	5.565	28 Days	5.55
2	2389.4	194.84	5.5129		
3	2443.1	196.5	5.56		
1	2384.4	205.42	5.8122	56 Days	6.12
2	2376.8	219.09	6.1992		
3	2332.1	224.72	6.3586		
1	2391.1	203.86	5.7681	90 Days	6.42
2	2389.4	212.63	6.0162		
3	2388.7	264.21	7.4754		

Table A.10: Splitting Tensile Strength Results Mix 5 - 1.25% TCF

Mix 5- 1.25% TCF					
#	**Mass(g)**	**Force(KN)**	**Tensile Strength (MPa)**		**Avarage**
1	2429.2	142.36	4.028	7 Days	4.45
2	2346.7	167.43	4.7373		
3	2366.7	161.53	4.5705		
1	2478.1	200.89	5.6842	14 Days	5.465
2	2450.7	183.4	5.1892		
3	2469.1	195.15	5.5216		
1	2511	178.79	5.0588	28 Days	5.49
2	2381.9	196.27	5.5533		
3	2300.1	207.35	5.8666		
1	2466.1	262.69	7.4328	56 Days	7.35
2	2414.6	252.78	7.1524		
3	2472.7	263.96	7.4687		
1	2385.5	267.4	7.5659	90 Days	7.54
2	2451.1	268.4	7.5942		
3	2442.4	264	7.4701		

A.4 Water Absorption Test

Table A.11: Water Absorption Test Mix 1-0% CF

Mix 1-0% CF					
#	**Wet Mass(g)**	**Dry Mass(g)**	**Differences**		**Avarage**
1	2432.1	2456.5	24.4	7 Days	24.79
2	2449	2474.4	25.4		
3	2464.33	2488.9	24.57		
1	2435.1	2462	26.9	14 Days	26.58
2	2350.2	2376	25.8		
3	2403.96	2431	27.04		
1	2426.86	2454.5	27.64	28 Days	28.58
2	2443.2	2471.6	28.4		
3	2439.4	2469.1	29.7		
1	2458.2	2489.1	30.9	56 Days	30.28
2	2452.4	2481.6	29.2		
3	2461.96	2492.7	30.74		
1	2437.4	2469	31.6	90 Days	31.25
2	2361.3	2392.6	31.3		
3	2398.55	2429.4	30.85		

Table A.12: Water Absorption Test Mix 2 - 1% UCF

Mix 2 - 1% UCF					
#	**Wet Mass(g)**	**Dry Mass(g)**	**Differences**		**Avarage**
1	2019.4	2091.3	71.9	7 Days	65.57
2	2154.6	2215.9	61.3		
3	2118.9	2182.4	63.5		
1	2112.8	2182.5	69.7	14 Days	73.13
2	2115.5	2195.1	79.6		
3	2133.4	2203.5	70.1		
1	2159	2248.3	89.3	28 Days	85.93
2	2112.8	2196.3	83.5		
3	2148.7	2233.7	85		
1	2129.8	2214.7	84.9	56 Days	90.23
2	2135.4	2230	94.6		
3	2121.5	2212.7	91.2		
1	2112.5	2204.1	91.6	90 Days	91.47
2	2053	2142.7	89.7		
3	2033.6	2126.7	93.1		

Table A.13: Water Absorption Test Mix 3 - 1% TCF

Mix 3 - 1% TCF					
#	**Wet Mass(g)**	**Dry Mass(g)**	**Differences**		**Average**
1	2317.8	2453.1	135.3	7 Days	28.40
2	2424.7	2346.2	-78.5		
3	2419.8	2448.2	28.4		
1	2401.4	2434.6	33.2	14 Days	33.03
2	2395.3	2428.1	32.8		
3	2425.4	2458.5	33.1		
1	2390.5	2424	33.5	28 Days	34.47
2	2404.4	2440.1	35.7		
3	2368.2	2402.4	34.2		
1	2395.8	2429.4	33.6	56 Days	35.40
2	2429.4	2467.9	38.5		
3	2458.7	2492.8	34.1		
1	2340.6	2375.2	34.6	90 Days	36.13
2	2286.9	2325.6	38.7		
3	2398.9	2434	35.1		

Table A.14: Water Absorption Test Mix 4 - 0.75% TCF

Mix 4 - 0.75% TCF					
#	**Wet Mass(g)**	**Dry Mass(g)**	**Differences**		**Average**
1	2464.5	2489.8	25.3	7 Days	26.20
2	2349.1	2375.1	26		
3	2451.5	2478.8	27.3		
1	2344.2	2372.8	28.6	14 Days	29.37
2	2341.8	2370.9	29.1		
3	2349.2	2379.6	30.4		
1	2368	2402	34	28 Days	34.37
2	2354.3	2389.4	35.1		
3	2409.1	2443.1	34		
1	2349.1	2384.4	35.3	56 Days	36
2	2340.4	2376.8	36.4		
3	2295.8	2332.1	36.3		
1	2351.5	2391.9	40.4	90 Days	40.87
2	2349.6	2389.4	39.8		
3	2346.3	2388.7	42.4		

Table A.15: Water Absorption Test Mix 5 - 1.25% TCF

Mix 5 - 1.25% Treated					
#	**Wet Mass(g)**	**Dry Mass(g)**	**Differences**		**Avarage**
1	2399	2429.2	30.2	7 Days	30.47
2	2316	2346.7	30.7		
3	2336.2	2366.7	30.5		
1	2444.5	2478.1	33.6	14 Days	32.83
2	2418.6	2450.7	32.1		
3	2436.3	2469.1	32.8		
1	2474.3	2511	36.7	28 Days	34.67
2	2348.8	2381.9	33.1		
3	2265.9	2300.1	34.2		
1	2429.3	2466.1	36.8	56 Days	36.90
2	2377.2	2414.6	37.4		
3	2436.2	2472.7	36.5		
1	2344.7	2385.5	40.8	90 Days	38.17
2	2413.7	2451.1	37.4		
3	2406.1	2442.4	36.3		

A.5 Dry Shrinkage Results

Table A.16: Dry Shrinkage Results Mix 1-0% CF

	Specimen 1		
Age	**Read**	**Difference**	**Dry shrinkage**
7	2.44		
14	2.388	0.052	0.0173
16	2.373	0.067	0.0223
18	2.373	0.067	0.0223
20	2.373	0.067	0.0223
			0.0211
	Specimen 2		
Age	**Read**	**Difference**	**Dry shrinkage**
7	3.119		
14	3.066	0.053	0.0177
16	3.057	0.062	0.0207
18	3.056	0.063	0.0210
20	3.056	0.063	0.0210
			0.0201
	Specimen 3		
Age	**Read**	**Difference**	**Dry shrinkage**
7	5.661		
14	5.602	0.059	0.0197
16	5.598	0.063	0.0210
18	5.597	0.064	0.0213
20	5.597	0.064	0.0213
			0.0208

Table A.17: Dry Shrinkage Results Mix 2 - 1% UCF

	Specimen 1		
Age	**Read**	**Difference**	**Dry shrinkage**
7	5.543		
14	5.435	0.108	0.0360
16	5.423	0.12	0.0400
18	5.423	0.12	0.0400
20	5.423	0.12	0.0400
			0.0390
	Specimen 2		
Age	**Read**	**Difference**	**Dry shrinkage**
7	7.097		
14	7.025	0.072	0.0240
16	6.977	0.12	0.0400
18	6.977	0.12	0.0400
20	6.977	0.12	0.0400
			0.0360
	Specimen 3		
Age	**Read**	**Difference**	**Dry shrinkage**
7	5.839		
14	5.767	0.072	0.024
16	5.718	0.121	0.0403
18	5.717	0.122	0.0407
20	5.717	0.122	0.04067
			0.0364

Table A.18: Dry Shrinkage Results Mix 3 - 1% TCF

	Specimen 1		
Age	**Read**	**Difference**	**Dry shrinkage**
7	7.829		
14	7.779	0.05	0.0167
16	7.768	0.061	0.0203
18	7.768	0.061	0.0203
20	7.768	0.061	0.0203
			0.0194
	Specimen 2		
Age	**Read**	**Difference**	**Dry shrinkage**
7	1.051		
14	1.003	0.048	0.0160
16	1.000	0.051	0.0170
18	1.000	0.051	0.0170
20	1.000	0.051	0.0170
			0.0168
	Specimen 3		
Age	**Read**	**Difference**	**Dry shrinkage**
7	4.313		
14	4.276	0.037	0.0123
16	4.262	0.051	0.0170
18	4.261	0.052	0.0173
20	4.261	0.052	0.0173
			0.0160

Table A.19: Dry Shrinkage Results Mix 4 - 0.75% TCF

	Specimen 1		
Age	**Read**	**Difference**	**Dry shrinkage**
7	6.377		
14	6.329	0.048	0.0160
16	6.286	0.091	0.0303
18	6.286	0.091	0.0303
20	6.286	0.091	0.0303
			0.0268
	Specimen 2		
Age	**Read**	**Difference**	**Dry shrinkage**
7	7.409		
14	7.339	0.07	0.0233
16	7.336	0.073	0.0243
18	7.336	0.073	0.0243
20	7.336	0.073	0.0243
			0.0241
	Specimen 3		
Age	**Read**	**Difference**	**Dry shrinkage**
7	5.615		
14	5.545	0.07	0.0233
16	5.536	0.079	0.0263
18	5.536	0.079	0.0263
20	5.536	0.079	0.0263
			0.0256

Table A.20: Dry Shrinkage Results Mix 5 - 1.25% TCF

	Specimen 1		
Age	**Read**	**Difference**	**Dry shrinkage**
7	4.603		
14	4.564	0.039	0.0130
16	4.561	0.042	0.0140
18	4.560	0.043	0.0143
20	4.560	0.043	0.0143
			0.0139
	Specimen 2		
Age	**Read**	**Difference**	**Dry shrinkage**
7	4.603	7.062	
14	4.564	7.032	0.030
16	4.561	7.017	0.045
18	4.560	7.017	0.045
20	4.560	7.017	0.045
			0.0138
	Specimen 3		
Age	**Read**	**Difference**	**Dry shrinkage**
7	5.608		
14	5.579	0.029	0.0097
16	5.563	0.045	0.0150
18	5.563	0.045	0.0150
20	5.563	0.045	0.0150
			0.0137

A.6 Durability

Table A.21 Durability- Oxygen Permeability Index

OPI						
Mix Description	**28 Days**		**56 Days**		**90 Days**	
	OPI	**Coefficient of permeability (m/s)**	**OPI**	**Coefficient of permeability (m/s)**	**OPI**	**Coefficient of permeability (m/s)**
Mix 1- 0% CF	10.07	9.337E-11	10.06	3.292E-10	10.19	1.254E-10
Mix 2- 1% UCF	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Mix 3- 1% TCF	9.9	1.594E-10	9.84	1.437E-09	9.95	1.876E-10
Mix 4- 0.75% TCF	9.89	1.151E-09	9.71	1.788E-10	9.73	1.955E-10
Mix 5- 1.25% TCF	10.14	8.870E-11	10.3	1.987E-10	10.05	1.665E-09

Table A.22 Durability- Sorptivity Index

Sorptivity						
Mix Description	28 Days		56 Days		90 Days	
	Sorptivity (mm/hr$^{0.5}$)	**Porosity (%)**	**Sorptivity (mm/hr$^{0.5}$)**	**Porosity (%)**	**Sorptivity (mm/hr$^{0.5}$)**	**Porosity (%)**
Mix 1- 0% CF	5.03	7.97	4.32	8.98	4.65	7.77
Mix 2- 1% UCF	21.73	25.9	17.95	21.8	24.92	29.4
Mix 3- 1% TCF	8.4	7.18	9.25	7.96	6.8	7.98
Mix 4- 0.75% TCF	9.79	9.19	6.3	7.89	9.27	7.90
Mix 5- 1.25% TCF	3.91	8.58	4.12	8.90	3.89	8.40

Table A.23 Durability- Chloride Conductivity Index

Conductivity (mS/cm)			
Mix Description	**28 Days**	**56 Days**	**90 Days**
Mix 1- 0% CF	0.59	0.67	0.6
Mix 2- 1% UCF	2.73	2.61	2.55
Mix 3- 1% TCF	1.26	1.25	0.89
Mix 4- 0.75% TCF	1.3	1.27	0.82
Mix 5- 1.25% TCF	0.72	0.76	0.62