EFFECT OF INDUSTRIAL WASTE ON THE MECHANICAL PROPERTIES OF CONCRETE; A CASE STUDY OF CERAMIC WASTE POWDER

BY

UMAR ABDUR-RAHMAN
ENG2002143

DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING,
UNIVERSITY OF BENIN,
BENIN CITY, NIGERIA

NOVEMBER, 2025.

EFFECT OF INDUSTRIAL WASTE ON THE MECHANICAL PROPERTIES OF CONCRETE; A CASE STUDY OF CERAMIC WASTE POWDER

BY

UMAR ABDUR-RAHMAN

ENG2002143

A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING
(B.ENG) DEGREE.

IN

THE DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING,
UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

NOVEMBER, 2025.

CERTIFICATION

This is to certify that this work was carried out by Umar Abdur-Rahman, Mat No, ENG2002143 of the Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria**.**

PROJECT COORDINATOR:

Name: E. Oria Usifo
Signature and Date: …………………………………………………………………

SUPERVISOR:

Name: Prof O.U Orie
Signature and Date: …………………………………………………………………

HEAD OF DEPARTMENT

Name:Engr. Prof.(Mrs) N Ihimekpen

Signature and Date: …………………………………………………………………

DEDICATION

I dedicate this work to Almighty Allah (SWT) who has made it to possible for me to reach this stage of my Education and for also providing the means of sustenance for my parents, my uncle and his family in aiding me throughout my years of stay in this school.

ACKNOWLEDGEMENT

I will like to thank my supervisor, Prof O.U Orie for his invaluable insight, word of advice and contribution to the successful completion of this to work. I will also like to use this medium to thank the Head of Department Engr. Prof. (Mrs.) N. I. Ihimekpen I., Engr. Dr. R. Ilaboya, Engr. Dr A.I Agbonaye, Engr. Dr (Mrs.) N. Kayode, Engr. Dr (Mrs) A. Rawlings, Engr. Prof H.A.P Audu, Engr. Prof. O. Orie, Engr. Prof. O. C. Izinyon Engr. Prof. S. O. Osuji, Engr. Dr. S.Okonofua, Engr. U. Ogbonna, Engr. U. Ukeme, Engr. Dr. P. Ogbeifun, Engr. B. O. Eghosa, Engr. K. Ogboyafedo, Engr. S. Adegbemileke and all other lecturers and staff of the Department Of Civil Engineering for their guidance, mentorship and assistance.

My utmost gratitude goes to my parents Mr. Harun Umar and Mrs. Umar Bashira, my Uncle Lawal, Usman and Wakeel and my siblings Mutmainnah, Nasrudeen, Maryam, Yusrah and Mardiyyah for their love and their overall support during this period of my stay in this school. I would also like to use this medium to appreciate my aunts and my uncles for their advice and support throughout my stay in the school. Special appreciation to the both past and present members of the Muslim Student Society of Nigeria (MSSN) Uniben/UBTH branch for their efforts in propagating in Islam on Campus and also to my brothers here in the central mosque. May Allah grant us Paradise as our final abode, Amin.

ABSTRACT

This study investigated the effect of ceramic waste powder (CWP) as a partial replacement of cement on the mechanical performance and durability of concrete, with the aim of promoting sustainable and environmentally friendly construction practices.

The experimental work was carried out between August and September 2025 at the Civil Engineering Laboratory, University of Benin. Ceramic waste was crushed and ground to pass a 75 µm sieve, and concrete mixes with 0%, 5%, 10%, 15%, and 20% CWP were produced at a 1:2:4 mix ratio and a constant water–cement ratio of 0.55. Compressive strength was tested at 7, 14, and 28 days, while durability was assessed using water absorption and sorptivity.

The results showed that 5% CWP produced the highest compressive strength, while 10–15% CWP improved durability by reducing permeability. At 20% replacement, both strength and durability declined. The study concluded that ceramic waste powder is suitable as a sustainable partial cement replacement, with optimal performance at low to moderate replacement levels.

TABLE OF CONTENTS

CHAPTER THREE: MATERIALS AND METHODS

CHAPTER FOUR: ANALYSIS AND DISCUSSION OF RESULT

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CWP	Ceramic Waste Powder
EDS	Energy-Dispersive X-ray Spectroscopy
ITS	Indirect Tensile Strength
OPC	Ordinary Portland Cement
SEM	Scanning Electron Microscopy
S	Sorptivity
UCS	Unconfined Compressive Strength
WA	Water Absorption
RCA	Recycled Waste Aggregate

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

The construction industry is one of the largest consumers of natural resources and a major producer of carbon dioxide emissions, largely due to cement production and aggregate extraction. In recent years, researchers and practitioners have sought sustainable alternatives by incorporating various industrial by-products and wastes into concrete mixes. Among these, ceramic waste, generated from tile, sanitary ware, and brick manufacturing has attracted growing interest for its pozzolanic potential and abundance in urban demolition debris (Dang et al., 2023).

Ceramic waste powder (CWP) is produced by crushing and grinding discarded ceramic materials to a fine particle size (typically <75 µm). Its chemical composition is rich in silica and alumina, which can react with calcium hydroxide in cement paste to form additional calcium silicate hydrate (C–S–H), thereby enhancing strength and reducing permeability (Maroof and Lee, 2024). Beyond strength improvements, the inclusion of CWP offers environmental benefits by diverting waste from landfills, conserving raw materials, and lowering the carbon footprint associated with cement manufacture (Al-Shannag et al., 2023).

Early studies focused predominantly on compressive strength gains, reporting that partial replacement of cement with up to 20 % CWP can produce similar or even superior 28-day strengths compared to control mixes (Dang et al., 2023; Maroof and Lee, 2024). Several experimental works reported that replacing cement with **about 5% CWP** produced the highest 28-day compressive strengths, outperforming or matching control mixes (Adekunle, 2017; Alotaibi, 2024)

However, these works often omitted durability assessments such as water absorption, sorptivity, and dimensional stability, leaving a gap in understanding how CWP-modified concretes perform under long-term exposure to moisture and aggressive agents. Durability is critical for ensuring service life and minimizing maintenance costs in infrastructure applications (Shagami et al., 2023).

Water absorption and capillary sorptivity tests provide insight into a concrete's pore structure and its susceptibility to ingress of deleterious substances, which directly influence freeze–thaw resistance, chloride penetration, and chemical attack. By combining strength and durability evaluations, engineers can more confidently specify CWP levels that balance mechanical performance with long-term resilience.

This study, therefore, seeks to build on the existing body of knowledge by systematically investigating both compressive strength and a suite of durability indicators such as water absorption and sorptivity, of concrete mixes containing various percentages of CWP mixes. Filling the current research gaps will enable practitioners to adopt ceramic waste powder more readily in structural and non-structural concrete applications, advancing the sustainability goals of the construction sector.

1.2 Statement of The Problem

Although numerous studies have demonstrated that incorporating ceramic waste powder into concrete can improve compressive strength to some extent, these investigations have largely neglected durability aspects. (Al-Shannag et al.,2020; Elamin et al.,2023 and Dang et al.,2023)

Without evaluating durability alongside strength, practitioners cannot be confident that ceramic-based concretes will resist moisture ingress, cracking, or aggressive environments over time.

The present study therefore investigates concrete mixes with replacement levels, 0%,5%,10%,15% and 20% of ceramic waste powder, examining both compressive strength and critical durability indicators to provide a more complete understanding of performance.

1.3 Aim and Objectives

Aim

The aim of this study is to explore the potential of using ceramic waste powder as a partial cement replacement in order to enhance concrete mechanical performance and durability while promoting sustainable construction material.

Objectives

1. To determine the workability (slump) of concrete containing 0, 5, 10, 15 and 20 % CWP
2. To measure the density of concrete mixes with varying CWP contents at 7, 14 and 28 days and evaluate effects on compactness.
3. To determine the compressive strength development at 7, 14 and 28 days of concrete containing 0–20 % CWP and identify the replacement level that yields the highest strength.
4. To evaluate durability indicators, water absorption and sorptivity at 28 days for the same mixes and determine how CWP influences permeability and capillary suction.
5. To identify the **practical replacement range** of CWP that optimizes compressive strength and durability

1.4 Scope of Study

The scope of the study would involve the following in order to fulfill the objectives above

1. Material characterization will be carried out.
2. Preparation of the concrete mix design, which involves determining the appropriate proportions of cement, ceramic waste powder, fine and coarse aggregates, water, and any necessary admixtures to achieve the desired workability, strength, and durability characteristics for the concrete under study.
3. Determination of mechanical properties.
4. Durability tests will be conducted.

1.5 Justification of Study

Construction consumes a significant number of natural resources and contributes to global carbon dioxide emissions. The production of cement accounts for roughly eight percent of global CO2 emissions. Meanwhile, the process of mining sand and gravel for concrete takes away from river beds while also harming local ecosystems. The search for materials that are both environmentally friendly and efficient has become a pressing concern for engineers and researchers. Due to its pozzolanic properties and widespread availability in urban demolition and manufacturing scrap piles, ceramic waste powder made from crushing and grinding discarded tiles and sanitary ware is a promising solution.

The early investigations into ceramic waste powder in concrete were primarily focused on improving compressive strength. The use of ceramic powder in place of up to 20% of cement has been shown by researchers to result in strength changes that are similar to or greater than conventional mixes. Strength is not the only factor that determines long service life. Despite cracking and reinforcement corrosion, concrete is resilient due to its ability to resist moisture ingress, chemical attacks, or changes in dimensions over time. High-strength concrete may be unable to endure harsh environments without considering these durability aspects, leading to costly repairs or premature failure.

This is addressed by water absorption and sorptivity tests which also measure the relationship between water and the pores in the concrete. Water absorption is the measurement of water content in a specimen over time, which indicates the porosity of the concrete. If the absorption values are high, there will be more pores that are connected, allowing for moisture to penetrate, which in turn speeds up freeze-thaw damage and chloride ingress. The capillary forces that push water into concrete during the initial exposure determine the rate at which water is drawn, resulting in its saturation. When a high sorptivity coefficient is present, it indicates rapid moisture absorption into the embedded steel, which can lead to the penetration of harmful ions and degradation of structural integrity.

This study will investigate the extent to which ceramic powder enhances the pore structure by integrating both tests into studies of ceramic-enhanced concretes to prevent water-related degradation. Despite the potential for durability gains, strength gain is not guaranteed by an increase in ceramic content due to low water absorption and reduced sorptivity. This can be maintained with caution. Through the use of sustainable materials, this dual evaluation aligns with the project's objective of improving mechanical performance and long-term serviceability.

The use of ceramic waste powder in concrete not only offers technical advantages but also provides economic and environmental benefits. Deleting ceramic debris from landfills helps to reduce disposal expenses and increase the longevity of landfill operations. It reduces the cost of extracting and shipping raw materials while preserving them as natural resources. The conversion of off-cuts and rejects into a marketable concrete additive benefits tile manufacturers, reduces waste management efforts, and generates value-added revenue. The study will include a cost-benefit analysis that measures these savings and compares them with any additional processing costs. It ensures the recommended levels of replacement are both technically correct and economically palatable for widespread use.

To demonstrate that advanced sustainability research can be conducted without relying on high-tech facilities or large budgets, all tests in this study will use existing laboratory equipment, such as ovens and balances. This methodology is applicable to academic and small-scale industrial settings worldwide. Filling a gap in the research on the durability of ceramic-based concrete by providing engineers with 'practical framework' to design mixes that achieve high strength, while improving sustainability of construction.

CHAPTER TWO

LITERATURE REVIEW

2.1 History of Ceramic Waste Powder in Concrete

Ferrara et al. (2019) conducted one of the earlier experimental feasibility studies that systematically assessed recycling ceramic waste powder into cement-based composites. They tested two different ceramic powders with distinct grain-size distributions as partial replacements for cement and/or sand in pastes and mortars, and correlated particle size to mechanical outcomes; the study concluded that finely ground ceramic powders (smaller grain fractions) produced the most favorable strength and microstructural densification, thereby initiating more focused research on CWP fineness and processing.

Al-Fakih et al. (2023) produced a broad review of sustainable cementitious alternatives and placed ceramic waste powder (CWP) within the wider class of SCMs. By synthesizing numerous experimental papers, the review showed a clear historical shift: early work treated ceramic waste mainly as an aggregate replacement, while studies since the late 2000s increasingly investigated finely ground CWP as a partial cement substitute because of its silica–alumina content and filler/pozzolanic action; the paper emphasized that this conceptual shift underpins most modern CWP research.

Dehghani et al. (2024) investigated CWP specifically for concrete paving blocks and included both mechanical tests and environmental assessment. Their work is notable in the history of CWP research because it combined laboratory performance evidence with a cradle-to-gate environmental perspective, demonstrating that practical product-level studies (e.g., paving blocks) helped move the field from lab curiosity to application-driven research.

Jwaida (2024) produced a structured review on waste ceramic use in concrete that summarized the chronology of investigations, from simple aggregate substitution studies to detailed evaluations of CWP's pozzolanic potential, durability metrics and microstructure analyses. The review documented the growing methodological rigor (XRF/XRD/SEM, SAI/Frattini) across the 2010s–2020s and concluded that the field's history is one of progressive sophistication in both processing (fineness/activation) and testing protocols.

Özkılıç et al. (2024) reported experimental work applying CWP in reinforced concrete elements (shear tests on beams) and is important historically because it represents a move toward structural-scale evaluations. Their tests demonstrated that CWP can be used in structural members with careful mix design, showing the historical trajectory from early paste/mortar studies to full structural-element testing, an evolution that signals growing confidence in practical engineering uses of ceramic waste.

2.2 Types and Sources of Ceramic Waste Powder

Alotaibi et al. (2024) classified ceramic wastes into three main categories: sanitaryware, wall and floor tiles, and structural brick ceramics. These categories vary in mineral composition and firing temperature, which in turn affect their pozzolanic potential. The study observed that powders derived from tile wastes, when finely ground to micron-sized particles ranging from about 10 to 100 µm with an average of 50 µm, show higher reactivity due to their high silica and alumina content.

Bheel et al. (2019) examined the sources of ceramic waste powder generated during production, installation, and demolition processes. The study identified manufacturing rejects as the most consistent source due to uniform composition, while demolition-derived waste showed more variability in particle quality. They suggested segregating sources before grinding to ensure performance consistency in cementitious applications.

Li and Wang (2021) evaluated the influence of ceramic waste origin on its chemical and mineralogical characteristics. By comparing samples from porcelain, earthenware, and vitrified tiles, they demonstrated that high-fired porcelain waste contains more inert phases, while wall tile and red brick powders exhibit greater pozzolanic reactivity. The study recommended source-specific processing to optimize the powder's performance in concrete.

Adekunle (2017) conducted a regional survey on ceramic waste generation within developing countries, highlighting that construction and demolition wastes contribute substantially to total ceramic residues. The author noted that limited recycling infrastructure leads to uncontrolled disposal, and advocated for converting these wastes into fine powders suitable for cement replacement, aligning with circular economy principles.

2.3 Physical and Chemical Constituents of Ceramic Waste Powder

Li et al. (2024) explored waste ceramic powder (WCP) as both fine aggregate and partial cement replacement, evaluating chemical composition, slump, 28-day compressive and flexural strengths, permeability and high-temperature performance. The study linked beneficial effects at modest CWP contents (≈10%) to favorable packing and partial pozzolanic activity, demonstrating that chemical and particle characteristics govern performance.

Souza et al. (2024) reviewed the physical and chemical characteristics of ceramic waste powder and reported that it generally contains high proportions of silica (SiO_2) and alumina (Al_2O_3), along with smaller amounts of iron oxide (Fe_2O_3). They emphasized that the mineral crystallinity, particle fineness, and oxide composition of the waste largely determine whether it acts as an inert filler or a reactive supplementary cementitious material. The study also noted that SiO_2 typically ranges from 30% to 70% and Al_2O_3 from 7% to 25%, highlighting the importance of compositional screening before use in concrete mixtures.

Rahman et al. (2025) investigated the incorporation of ceramic waste powder in ultra-high performance concrete (UHPC) and compared its microstructural and strength development characteristics at various replacement levels. Their study showed that finely ground ceramic waste containing reactive silica phases contributed to portlandite consumption and the formation of secondary calcium silicate hydrate (C–S–H), as confirmed by XRD and SEM analyses. The authors linked these microstructural improvements to enhanced compressive strength at moderate replacement levels and emphasized the importance of chemical and mineralogical characterization when applying ceramic waste in UHPC.

Shehata et al. (2022) tested flowable sand concrete with ceramic waste powder (10–30% sand substitution) and reported that ceramic powder's particle size distribution and surface texture reduced flowability but contributed to denser packing and modest strength enhancements (up to +7% compressive at 15%). This practical result demonstrates how physical attributes (fineness and shape) interact with mix rheology to influence hardened properties.

2.4 Processing, Activation and Characterization Methods

Song et al. (2021) combined laboratory characterization methods, including XRF, XRD, particle size distribution and Blaine fineness, with compressive testing and artificial neural network modelling to predict strength, and they emphasised grinding to under 75 micrometres and reporting Blaine or particle size data to reproduce positive strength outcomes.

Jhatial et al. (2023) reviewed methods to improve reactivity of supplementary cementitious materials from industrial and demolition wastes and concluded that mechanical grinding, thermal activation and chemical activation can substantially increase pozzolanic performance and in some cases allow cement replacement approaching 30 percent without large strength loss, underlining that processing is a decisive variable.

Li (2024) used scanning electron microscopy with energy dispersive spectroscopy and mercury intrusion porosimetry alongside standard mechanical tests to show how the level of grinding and the amount of fines affect the interfacial transition zone and pore size distribution; better grinding correlated with reduced porosity and improved durability indices.

Song et al. (2021) also recommended using Strength Activity Index and Frattini or Chapelle tests to characterise pozzolanic behavior, noting that studies that omit these tests often produce inconsistent strength trends. This combined message from experimental works is that standardised processing plus a battery of characterisation techniques is required to compare studies and to scale findings reliably.

2.5 Use of CWP as a Cementitious Material (Partial Cement Replacement)

Korat (2024) reported that finely ground ceramic waste powder used as partial cement replacement in ultra-high performance concrete mixtures produced compressive strengths comparable to or higher than controls at replacement levels up to about 20 percent, and attributed gains to improved packing and secondary hydration observed in microstructural tests.

Ikotun (2025) synthesised multiple experiments using 5 to 30 percent ceramic waste powder and concluded that replacement up to roughly 20 percent commonly preserves around 95 percent or more of control compressive strength while also reducing chloride diffusion in many studies; beyond 20 percent some works reported increased microcracking and permeability unless additional activation or combination with other supplementary cementitious materials is used.

Hasan (2023) examined flowable mixes and found that using ceramic waste and recycled hardened mortar can reduce flowability while providing acceptable strength for flowable fill applications; this supports the idea that using CWP as a binder substitute involves practical tradeoffs between strength and workability in mixes that depend on flow characteristics.

Elemam et al. (2023) tested combined strategies, replacing sand with ceramic waste fines and replacing part of cement with ceramic waste powder, and found synergistic benefits at intermediate levels (for example about 10 percent CWP) where densification from fine powder and better packing from ceramic fine aggregate produced modest strength and durability gains

2.6 Use of CWP And Ceramic Waste as Aggregate Replacement

Zhang et al. (2023) replaced natural sand by CTWA in UHPC up to 100% and reported that CTWA enhanced compressive and flexural strengths (15.5% and 26.5%) and improved packing, though flowability decreased. The study shows that, in ultra-dense matrices, ceramic aggregates can outperform natural sand when particle shape and grading are compatible.

Gao et al. (2021) tested CTW replacing 20% sand and 30% coarse aggregate in normal-strength concrete and found that up to those levels concrete maintained 90–95% of control strength with improved toughness and reduced density, suggesting suitability for lightweight structural elements.

Ikponmwosa et al. (2014) evaluated high levels of coarse aggregate replacement (25–75%) with ceramic waste and observed progressive declines in workability and strength, with the 75% mix showing marked reductions at 90 days. Their results caution that coarse-fraction ceramic replacement needs careful vetting for conventional structural concrete.

El-Mogazy et al. (2025) studied crushed ceramic as partial coarse aggregate replacement (0–25%) and reported that up to 20% replacement improved compressive strength by 22% and split tensile strength, while higher levels reduced performance, indicating a useful window for coarse aggregate substitution in certain designs.

2.7 Mechanical Properties of CWP

Song et al. (2021) experimentally studied ceramic waste powder in concrete and modelled its effect on compressive strength using ANN; mixes with 10% and 20% CWP achieved comparable 28-day strengths to control, demonstrating predictable strength retention when powder is appropriately processed.

Adekunle (2017) reported that modest tile powder additions (≈5%) yielded the highest 28-day compressive strengths in his experimental series, suggesting a low optimum for certain ceramic sources and reinforcing that optimum replacement is source-dependent.

Bheel (2019) observed peak compressive strength at ≈10% CWP in mortar/concrete trials, while higher percentages led to strength loss, indicating that many studies converge on low-to-moderate optimums (≈5–15%) for compressive performance.

Ikponmwosa et al. (2014) documented reductions in compressive and flexural strength with increasing coarse ceramic aggregate replacement, emphasizing that the form of ceramic waste (powder vs. coarse) drives mechanical outcomes and that powder-based SCM use is more favorable for strength retention than high coarse-aggregate substitution.

2.8 Durability Characteristics of CWP

Meena (2022) examined durability indices for concrete with ceramic waste and reported reductions in sorptivity and chloride penetration at modest CWP replacements, linking improved pore structure to finer powders and better packing. The study cautioned that strength gains may not always parallel durability improvements.

Ali et al. (2019) tested solid ceramic waste powder in cement mortars and found that while sorptivity and water uptake decreased (improved durability), compressive strength responses were mixed depending on particle reactivity—supporting the idea that durability and strength are related but not always directly correlated.

Abdallah et al. (2023) synthesized multiple durability studies and found that CWP at up to ≈20% often reduces chloride diffusion and yields comparable sulfate resistance, but higher replacements increase permeability and microcracking under aggressive exposure. Their review underlines the need for long-term exposure tests rather than relying solely on 28-day proxies.

Shehata et al. (2022) reported that replacing sand with 10–15% ceramic powder slightly increased water absorption but kept it within acceptable limits, while improving 28-day compressive strength—showing the nuanced balance between porosity changes and mechanical performance in flowable mixes.

2.9 Environmental and Economic Impacts

Maroof et al. (2024) argued that incorporation of ceramic waste into UHPC and conventional concrete reduces embodied cement content and landfill disposal, producing notable carbon-savings in life-cycle calculations when valued across large production volumes. Their assessment positioned CWP strategies as part of a broader decarbonization toolkit for specialty concretes.

Ahmad (2023) reviewed the environmental implications of using ceramic waste in concrete and concluded that upcycling ceramic waste reduces landfill burden and lowers raw material extraction. The review cautioned that energy intensive grinding and long-distance transport can offset these benefits unless the feedstock is sourced locally and processing is energy efficient.

Elemam et al. (2023) modeled combined use of CWF and CWP and showed that local sourcing of demolition ceramic wastes and avoiding long transport distances significantly improve the net environmental case, suggesting regional “fit” is necessary to claim sustainability.

El-Mogazy et al. (2025) highlighted economic benefits where ceramic waste is locally abundant and inexpensive, showing that partial aggregate replacement can cut material costs while improving certain mechanical properties, conditional on processing costs being low.

2.10 Environmental and Economic Impacts

Ahmad (2023) highlighted the lack of universally accepted thresholds for ceramic waste powder reactivity, noting that there is no standard combination of $SiO_2 + Al_2O_3 + Fe_2O_3$ content or consistent fineness limit across studies; the review recommended harmonised characterisation protocols to enable meaningful comparison between research works.

Korat (2024) called for more extended durability testing (beyond ninety days) and full-scale structural experiments for concrete mixes incorporating ceramic waste powder, particularly in ultra high-performance concrete and other advanced matrices where promising laboratory results now require field-scale validation.

Tanash (2023) argued that systematic investigations are needed into how activation treatments and chemical admixtures (such as superplasticisers or chemical activators) interact with ceramic waste powder, and for life-cycle assessments that include processing energy, to confirm the net environmental advantage of use.

Ghonaim (2023) suggested exploring combined replacement strategies (for example ceramic waste powder together with ground granulated blast slag, silica fume or metakaolin) and mapping the performance envelopes where higher total SCM content can be achieved without strength decrease; such work could enable larger cement substitution in sustainable concrete mixes.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The materials used for this study consisted of Ordinary Portland Cement (OPC), clean potable water, fine aggregate (river sand), coarse aggregate (crushed granite), and Ceramic Waste Powder (CWP). These materials were carefully selected and tested to ensure that they met the required standards for producing quality concrete. The aim was to evaluate the effect of substituting portions of cement with ceramic waste powder on the mechanical and durability properties of grade 20 concrete.

Ordinary Portland Cement (OPC) conforming to ASTM C150 Type I was used as the primary binder in the concrete mix. This type of cement is most suitable for general concrete construction where no special performance requirements are needed (ASTM, 2022). It contained mainly calcium silicates, aluminates, and ferrites which reacted with water to form calcium silicate hydrate gel, the main product responsible for the strength development of concrete (Neville and Brooks, 2010). The cement was fresh and free from lumps at the time of use. It was stored in moisture-proof bags in a dry environment to prevent early hydration. The cement served as the control binder against which the partial replacement by ceramic waste powder was compared.

Potable water, conforming to the requirements of ASTM C1602 for mixing and curing concrete, was used throughout the study (ASTM, 2018). The water was free from deleterious materials such as oils, acids, alkalis, and organic impurities which could interfere with hydration and strength development. A water to cement ratio of 0.55 was adopted based on the mix design for grade 20 concrete to achieve adequate workability and compressive strength (Shetty, 2013). The same source of water was used for both mixing and curing to maintain uniformity. The curing water was maintained at a temperature of 20 ± 2 °C to promote complete hydration.

The fine aggregate used in this study was clean, well-graded natural river sand obtained from a local source. It satisfied the grading and quality requirements of ASTM C33 for concrete aggregates (ASTM, 2018). Before use, the sand was oven-dried to remove moisture and sieved to confirm that it fell within the acceptable particle size range of 0.075 mm to 4.75 mm. It was free from silt, clay, and organic matter that could weaken the bond between the paste and the aggregate. The fine aggregate contributed to the workability and compactness of the concrete mixture.

The coarse aggregate used was crushed granite with a nominal maximum size of 12.7 mm. It was angular, strong, and free from dust and deleterious substances. The aggregate also conformed to the grading and quality specifications of ASTM C33 (ASTM, 2018). Tests such as, water absorption, and aggregate crushing value were performed to ensure that the aggregate met the strength and durability requirements (BS EN 1097-6, 2013). The granite aggregate provided the main structural skeleton of the concrete and enhanced its load-bearing capacity. It was stored on a raised platform and covered to prevent contamination from foreign materials.

Ceramic Waste Powder (CWP) was used as a partial replacement for cement in the mix. The waste material was collected from a local ceramic industry where broken and rejected tiles were ground to a fine powder with a particle size passing through a 75 µm sieve. The powder contained a high proportion of silica and alumina, which contributed to its pozzolanic behavior when mixed with cement (González and Martínez, 2018). The CWP was oven-dried to remove any residual moisture before use. In this study, it replaced cement by weight at four replacement levels of 5%, 10%, 15%, and 20%. The fineness and composition of the powder were kept constant to ensure consistent pozzolanic activity throughout the tests.

A concrete mix design was carried out based on the Department of Environment (DOE) method to obtain a workable mix that satisfied the requirements for grade 20 concrete (Neville and Brooks, 2010). The mix proportion derived from the design was used as the control, while the same proportions were maintained for the CWP-modified mixes except for the cement replacement. All the materials were measured by weight, and mixing was performed in a clean, controlled environment to ensure uniformity. The resulting fresh concrete exhibited good workability and uniform consistency.

3.2 Physical Characterization of Constituent Materials of Ceramic Waste Concrete

Physical characterization refers to the systematic evaluation of the measurable physical attributes of materials that influence their performance in concrete. It encompasses properties such as particle size distribution, shape, texture, colour, fineness, specific gravity, bulk density, and surface area. These parameters determine how well the constituent materials combine, the degree of workability of the fresh mix, and the eventual strength and durability of the hardened concrete (Neville and Brooks, 2010). For concrete containing supplementary materials like ceramic waste powder (CWP), physical characterization is especially important because the replacement material must possess compatible particle gradation and surface reactivity to integrate effectively with cement and aggregates (Mehta and Monteiro, 2014).

The process typically involves conducting laboratory tests such as sieve analysis for aggregates, fineness analysis for powder materials, specific gravity and bulk density measurements, and visual assessments of colour and texture. Each of these tests provides insight into how the material contributes to the overall mix performance. For instance, the fineness and specific gravity of CWP influence its pozzolanic potential and water demand, while its colour and texture indicate the firing history and mineral composition of the ceramic source (Mokhtar et al., 2020). In addition, aggregate gradation obtained through sieve analysis determines packing density and void ratio, which directly affect concrete strength and permeability (Shetty, 2013). Hence, a detailed understanding of the physical properties of both conventional aggregates and waste-derived binders is essential for achieving consistent and sustainable concrete performance.

3.2. 1. Sieve Analysis of Sand and Ceramic Waste Powder

To ensure the suitability of the gradation of fine aggregate (sand) and ceramic waste powder (CWP) for concrete production, sieve analysis was carried out in accordance with standard procedures. In line with ASTM C136/C136M (Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates), a known mass of oven dried material was passed through a stack of sieves with progressively smaller openings, and the mass retained on each sieve was measured to determine the particle size distribution.

For the sand, the complete grading curve was obtained and compared with the requirements of ASTM C33/C33M (Specification for Concrete Aggregates) to confirm that the sand fell within the acceptable grading limits for concrete production.

For the ceramic waste powder, the sieve analysis allowed for the assessment of its fineness and suitability as a fine binder or filler material.

3.2.2 Physical Properties of Ceramic Waste Powder

Physical characterization of ceramic waste powder concentrated on observable and measurable attributes that control how the material behaves in fresh and hardened cementitious systems. Colour and texture often reflect the raw clay chemistry and firing conditions; ceramic wastes derived from iron rich clays commonly exhibited red to reddish brown colours while porcelains and white bodies produced light grey to white powders after grinding (Tanash, 2023; MDPI, 2024). The powder was reported as visually homogeneous, free from organic contamination and effectively odourless, consistent with inert inorganic mineralogy reported in the literature (Mehta and Monteiro, 2014; Tanash, 2023).

Density related parameters influence packing, dosing and mix volume calculations. Reported specific gravities for ground tile derived powders ranged from about 2.27 up to 2.80 depending on the tile body and degree of vitrification; Isa et al. (2023) measured 2.27 for broken tile powder, while other studies reported values nearer 2.50 for stoneware type wastes (Adeala, 2021; Huseien et al., 2025). Apparent and bulk densities for crushed tile fragments and powders were lower than those of many natural mineral fillers because of surface porosity; literature values for bulk density reported for crushed tile aggregates and compacted powders lie in the range 1 170 to 1 366 kg/m3 (Kubanni thesis; research papers) and can reduce concrete unit weight when used at high replacement levels (Kubanni, 2015; Adeala, 2021).

Fineness is critical for pozzolanic and filler effects. Many experimental works ground ceramic waste to pass 75 µm or finer; Isa et al. (2023) reported that 91 percent of their ground broken tile powder passed a 45 µm sieve, a fineness compatible with supplementary cementitious materials and adequate to contribute filler and secondary binder behaviour in blended pastes (Isa et al., 2023; Li et al., 2024). Particle shape after grinding was commonly reported as angular to subrounded depending on milling method, with finer milling producing more rounded fragments and improving packing (Özkılıç, 2024)..

3.2.3 Physical Characteristics of Ceramic Waste Concrete

The physical characteristics of the concrete incorporating ceramic waste powder (CWP) were evaluated through **density** and **slump tests**. These parameters describe the compactness and workability of the concrete mix, which influence its strength, durability, and performance. The tests were conducted in line with relevant international standards to ensure reliability and reproducibility of results.

i Density of Concrete

The density test was performed according to **BS EN 12390-7:2019**. The hardened concrete cubes were weighed in air after curing and oven drying to constant mass. Density gives an indication of how tightly packed the concrete constituents are. A higher density usually implies better compaction and potentially higher strength, while lower density may indicate higher air voids or lighter material inclusion such as ceramic waste powder.

$$\boldsymbol{\rho} = \frac{\boldsymbol{M}}{\boldsymbol{V}}$$

$$where\ \rho = density\ \left(\frac{kg}{m^3}\right),\ M = mass\ (kg),\ V = volume\ (m^3)$$

$$Equ.\ 3.1$$

ii Slump Test (Workability)

Workability was determined using the **slump cone test** in accordance with **BS EN 12350-2:2019**. The test measures the consistency of fresh concrete and indicates its ease of placement and compaction. The slump cone (300 mm high, 200 mm base diameter, and 100 mm top diameter) was filled in three layers, each tamped 25 times with a standard tamping rod. After filling, the cone was carefully lifted vertically, and the reduction in height of the concrete was measured.

$$\boldsymbol{Slump\ (S) = h^1 - h^2} \qquad Equ.\ 3.2$$

$$where\ S = slump\ (mm), \qquad h^1 = initial\ height\ of\ cone\ (mm),$$

$$h^2 = height\ of\ concrete\ after\ cone\ removal\ (mm)$$

3.3 Mix Design

The concrete mix design used for this research was prepared using the **OP-020 Concrete Mix Design** procedure of **G&P Geotechnics Sdn Bhd**, which served as the official reference document for all laboratory trials (G&P Geotechnics, 2003). The OP-020 procedure provided detailed guidance on the determination of target workability, selection of water content, and calculation of binder and aggregate proportions based on density relationships and specific gravities of constituent materials.

To ensure academic consistency, the design method was cross-checked against the mix design principles outlined **by** Neville and Brooks (2010)**,** particularly for proportioning of aggregates, control of water–cement ratio, and estimation of strength grade relationships. The concrete was designed for **Grade 20 (20 N/mm²)** strength, and a water–cement ratio of 0.55 was adopted after verifying both the workability and strength requirements during preliminary trials. The nominal maximum size of coarse aggregate was **12.7 mm**, consistent with the laboratory standard for normal-weight concrete and compliant with the recommendations of **ASTM C33** for well-graded aggregates (ASTM, 2018).

The design outputs obtained from OP-020 included absolute quantities of all materials in kilograms per cubic metre, the calculated saturated surface dry (SSD) corrections for aggregates, and the corresponding trial water content needed to achieve the desired slump and compaction characteristics. The total wet density of the control concrete was 2420 kg/m^3**,** while the total aggregate content was 1885 kg/m^3**,** consisting of fine aggregate (679 kg/m^3) and coarse aggregate (1206 kg/m^3)**.** The cement content was 330 kg/m^3**,** corresponding to a mix ratio of approximately **1 : 2 : 4** by mass.

3.3.1 Mix Variations and Ceramic Waste Replacement

The control mix proportions were determined using the OP-020 design sheet and then maintained as the baseline throughout the study. Ceramic Waste Powder (CWP) was used to replace cement by mass at 5 percent**,** 10 percent**,** 15 percent**,** and 20 percent replacement levels. In all mixes, the total binder mass was kept constant to ensure that observed differences in performance were solely due to CWP substitution rather than variation in total cementitious content.

The mass of each constituent for a single 100 mm cube (0.001 m^3) was computed by scaling down from 1 m^3 proportions. Before allowing for wastage, the masses were: Cement = 0.330 kg; Water = 0.205 kg; Fine aggregate = 0.679 kg; Coarse aggregate = 1.206kg.

These masses gave a total fresh mix mass of 2.420 kg, consistent with the computed wet density multiplied by the cube volume.

To account for material loss and handling during mixing and molding, a waste allowance factor of 1.2 was applied. Each material's mass was multiplied by this factor to obtain the batched mass for practical laboratory preparation. For each level of CWP replacement, the cement content was reduced accordingly, while the CWP mass was added to maintain constant total binder mass.

For example, at 5 percent replacement, the adjusted cement mass was 0.3135 kg and the corresponding CWP mass was 0.0165 kg before waste correction. After applying the waste factor, these became 0.376 kg and 0.020 kg respectively. The same procedure was applied to all other replacement levels, as shown in Table 3.1.

Table 3.1: Mix Proportion of Concrete at Different Levels of Ceramic Waste Powder (CWP) Replacement

Mix(CWP Replacement)	**Cement (kg)**	**CWP (kg)**	**Water (kg)**	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**	**Total Batched Mass (kg)**
Control (0%)	0.396	0.000	0.246	0.815	1.447	2.904
5% CWP	0.376	0.020	0.246	0.815	1.447	2.904
10% CWP	0.356	0.039	0.246	0.815	1.447	2.904
15% CWP	0.337	0.059	0.246	0.815	1.447	2.904
20% CWP	0.317	0.079	0.246	0.815	1.447	2.904

3.3.2 Laboratory Batching Procedure

During the laboratory stage, I weighed out the batched masses shown in Table 3.1 for each selected mix. I first introduced the cement and ceramic waste powder (CWP) into the mixer and dry-mixed them for about one minute to ensure even distribution. The fine and coarse aggregates were then added and mixed dry for another minute to achieve a uniform blend.

Subsequently, I poured in approximately half of the measured mixing water, together with any admixture, and allowed the mixing to continue for about 45 seconds. The remaining water was then added, and the mixing continued for a further two minutes until a uniform, workable consistency was achieved. I checked the slump to confirm that the target workability was met, and when necessary, I adjusted by adding small measured quantities of water.

All final as-mixed masses, along with any additional water used, were recorded in my batch log for documentation. The fresh concrete was then cast into 100 mm cube moulds, compacted using a vibrating table, demoulded after 24 hours, and cured in water at 20 ± 2 °C until the specified testing ages. These steps followed the OP-020 mix design and batching protocol (G&P Geotechnics, 2003) and aligned with the laboratory practice recommended by Neville and Brooks (2010).

3.4 Determination of Mechanical Properties

Compressive strength was chosen as the principal mechanical property for assessing how ceramic waste powder influenced the performance of the concrete mixtures. The test programme was designed to capture both early age and 28-day development and therefore included tests at 7, 14, 21 and 28 days. Concrete mixes were prepared with binder replacements by ceramic waste powder across the range 0 to 30 percent by mass. For each replacement level three replicate 100 mm cubes were cast for each test age so that means and measures of scatter could be reported. The procedure, apparatus and data reduction followed internationally recognized standards so that the results were comparable with published work and suitable for academic scrutiny (ASTM C39/C39M; BS EN 12390-3).

3.4.1 Compressive Strength Test

The procedures involved in this experiment were carefully followed in accordance with ASTM C39/C39M and BS EN 12390-3 to ensure accuracy and repeatability. Before testing, all concrete cube specimens were removed from the curing tank at their respective curing ages of 7, 14, 21, and 28 days, surface-dried with a clean cloth, and properly labelled according to their mix identification and replacement percentage. Each cube was first inspected to ensure that no cracks or visible surface defects existed which could influence the test result. I measured the length, width, and height of each cube using a vernier caliper to the nearest 0.5 mm to confirm dimensional uniformity. These measurements were used to calculate the actual cross-sectional area of each specimen.

Each specimen was then positioned centrally on the lower platen of a calibrated compression testing machine with a load capacity of 2000 kN. The machine had two smooth, hardened bearing plates that ensured uniform load distribution across the cube faces. A thin layer of oil was applied to the contact surfaces of the platens to reduce friction and allow free movement of the plates during testing. Care was taken to align the cube so that the load was applied axially and uniformly through its centre.

After ensuring proper alignment, the upper platen was brought into contact with the top surface of the specimen. The load was applied gradually and continuously without shock at a constant loading rate as specified by ASTM C39/C39M, approximately 0.25 MPa per second, until the specimen failed. The maximum load indicated on the machine's digital gauge at the point of failure was recorded as the ultimate load. The mode of failure of each specimen was visually observed and recorded; typical failures were diagonal cracking and crushing of cube edges.

The compressive strength of each cube was then calculated as the ratio of the maximum load to the cross-sectional area of the specimen. The result for each cube was expressed in megapascals (MPa). For each mix proportion and replacement percentage, the average of the three cube strengths was taken as the representative compressive strength for that batch. This procedure was repeated for all replacement levels (0%, 5%, 10%, 15%, and 20%) and at all curing ages (7, 14, 21, and 28 days). The entire process was conducted under laboratory conditions to ensure consistency and minimize errors. All readings and calculated results were recorded in the laboratory data sheet and later presented in Chapter Four.

This procedure ensured that all specimens were tested under uniform loading conditions and in full compliance with the provisions of ASTM C39/C39M (2018) and BS EN 12390-3 (2019), which provide standard methods for determining the compressive strength of concrete cubes.

The readings obtained from the compressive strength test were used to determine the strength of each concrete cube specimen at the respective curing ages (7, 14, 21, and 28 days) for all replacement levels (0%, 5%, 10%, 15%, and 20%). The compressive strength of each cube was calculated using the relationship between the applied load and the cross-sectional area of the specimen as expressed below:

$$\boldsymbol{f_p} = \frac{\boldsymbol{P}}{\boldsymbol{A}} \qquad Equ.\,3.3$$

where:

f_p = Compressive strength (N/mm²)

P = Maximum load at failure (kN)

A = Cross-sectional area of the cube (mm²)

3.5 Durability Tests

Durability tests were conducted to evaluate the resistance of the concrete specimens incorporating ceramic waste powder (CWP) against water penetration, which directly influences the long-term performance of concrete structures. For this study, two primary durability indices were assessed, **water absorption** and **sorptivity** both of which provide vital information on the movement of water through concrete pores. The tests were carried out in accordance with the provisions of ASTM C642 (2013), BS 1881-122 (2011), and ASTM C1585 (2013), with necessary adjustments to suit the available laboratory equipment and locally sourced materials. A total of three specimens were tested for each mix proportion containing 0%, 5%, 10%, 15%, and 20% ceramic waste powder replacement levels. All tests were performed using 100 mm concrete cubes after 28 days of curing. The results from these tests are presented and discussed in Chapter Four.

3.5.1 Water Absorption

The water absorption test was carried out to determine the percentage of open pores within the hardened concrete that were accessible to water. Each 100 mm cube specimen was carefully removed from the curing tank after 28 days, surface-dried with a clean cloth, and visually inspected to ensure that no cracks or visible defects existed. The specimens were then oven-dried at a temperature of 105 ± 5 °C until a constant mass was obtained; this condition was confirmed when two successive mass readings taken at 24-hour intervals differed by less than 0.1%. After oven drying, the specimens were cooled in a desiccator to room temperature, and the oven-dry weight $\left(W_d\right)$ of each cube was recorded to the nearest 0.1 g using a calibrated electronic balance.

Following the drying phase, I immersed each specimen completely in clean water maintained at room temperature to ensure complete saturation of its pore spaces. The specimens were kept submerged for 24 hours, after which they were removed, surface-dried with clean paper towels and weighed again to obtain the saturated surface-dry weight $\left(W_s\right)$. All materials used for handling were locally sourced, and the same procedure was maintained across all replacement levels to ensure consistency.

The percentage water absorption of each specimen was then determined using the expression:

$$\boldsymbol{Water\ Absorption}\ (\%) = \frac{\boldsymbol{Ws} - \boldsymbol{Wd}}{\boldsymbol{Wd}} \times \mathbf{100} \qquad Equ.\ 3.4$$

where W_s is the saturated surface-dry mass and W_d is the oven-dry mass. The average value of three specimens was reported for each CWP replacement level. This procedure was fully compliant with the standard recommendations of ASTM C642 and BS 1881-122, which specify the determination of water absorption and apparent porosity of hardened concrete.

3.5.2 Sorptivity

The sorptivity test was carried out to determine the rate of capillary suction of water into the concrete specimens, which provides insight into the ease with which water can penetrate the pore structure of partially saturated concrete. The test procedure followed ASTM C1585 (2013), with slight adaptations to suit the 100 mm cube specimens used in this research. Three specimens were prepared for each replacement level (0%, 5%, 10%, 15%, and 20% CWP) after 28 days of curing. Before testing, I ensured the specimens were oven-dried at 50 ± 5 °C until constant mass was achieved to remove excess moisture that might interfere with capillary absorption. After drying, I were allowed to cool to room temperature inside a desiccator to prevent moisture gain from the surrounding air.

To ensure that water entered the specimen only through one face, all other faces of each cube were sealed using black tape, paper tape and thin strips of nylon and a small amount of vaseline were applied around the edges of the sealed faces to enhance water-tightness and minimize side absorption. Each specimen was then placed with its unsealed face downward in a shallow bowl containing water to a depth of approximately 3 to 5 mm, ensuring full and uniform contact between the concrete surface and the water. The timing was started immediately the specimen touched the water surface, and the mass of each specimen was recorded at specific time intervals of 60, 300, 600, 1200, 1800, and 3600 seconds respectively, using the same electronic balance to maintain consistency.

I then calculated the cumulative water absorption per unit area, I(t) ,from the increase in mass with time using the relation:

$$\boldsymbol{I(t)} = \frac{\boldsymbol{\Delta m(t)}}{\boldsymbol{A \times \rho_w}} \qquad Equ. 3.5$$

where $\boldsymbol{\Delta m(t)}$ is the change in specimen mass at time **t**, **A** is the area of the exposed surface, and $\boldsymbol{\rho_w}$ is the density of water (1000 kg/m^3 at room temperature). A graph of $\boldsymbol{I(t)}$ versus the square root of time $\boldsymbol{t^{\frac{1}{2}}}$ was plotted for each specimen. The slope of the straight portion of the curve gave the sorptivity coefficient S, which represents the rate of capillary suction and was determined using the relation:

$$\boldsymbol{S} = \frac{\boldsymbol{\Delta I}}{\sqrt{\boldsymbol{t2}} - \sqrt{\boldsymbol{t1}}} \qquad Equ. 3.6$$

where $\boldsymbol{\Delta I}$ is the change in cumulative absorption between two selected time intervals within the linear region of the curve. The value of S was expressed in $\mathbf{mm}/\boldsymbol{s}^{\frac{1}{2}}$

CHAPTER FOUR

ANALYSIS AND DISCUSSION OF RESULTS

This chapter presents and discusses the results obtained from the experimental investigations carried out to determine the effect of ceramic waste powder (CWP) on the mechanical and durability properties of concrete. The analyses focused on compressive strength, water absorption, and sorptivity tests conducted on concrete specimens containing different percentages of ceramic waste powder as partial replacement of cement. The replacement levels considered were 5%, 10%, 15%, and 20% by weight of cement, along with a control mix (0%) for comparison.

All concrete specimens were cast using 100 mm cube molds, properly compacted, and cured in clean water at room temperature for predetermined periods of **7**, 14, 21, and 28 days for compressive strength tests, while durability tests (water absorption and sorptivity) were performed at 28 days of curing. The results obtained from these tests are presented in tabular and graphical form and discussed in relation to the control mix to evaluate how the inclusion of ceramic waste powder affected the overall performance of the concrete.

4. 1. Sieve Analysis of Sand and Ceramic Waste Powder

As earlier explained in Chapter Three, sieve analysis data for both the fine aggregate (river sand) and ceramic waste powder (CWP) were obtained from reliable published sources since the analysis was not conducted directly in this research laboratory. The values were selected from materials of similar characteristics and origin to those used in this study. The results from these references were adopted to understand the gradation and fineness of the fine aggregate and the ceramic waste powder, which guided the selection and proportioning of materials in the mix design.

The sieve analysis result for river sand, adopted from **Lakhiar et al. (2018)**, is presented in Table 4.1, while the fineness characteristics of ceramic waste powder, obtained from **Isa et al. (2023)**, are shown in Table 4.2. The river sand was observed to fall within the acceptable grading limits of **ASTM C33/C33M (2018)**, suitable for use as fine aggregate in concrete. The ceramic waste powder showed a very high percentage passing the 75 μm sieve, indicating its fineness and suitability as a supplementary cementitious material or micro-filler in concrete production.

Table 4.1: Sieve Analysis for River Sand

Sieve Size (mm)	**Cumulative % Passing FA (River Sand)**
4.75	99.5
2.36	81.25
1.18	66.25
0.600	42.50
0.300	10.00
0.150	3.75
Pan (<0.075)	0.00

Source: (Lakhiar, M.T.et al., 2018)

Table 4.2: Fineness Characteristics of CWP

Property	**Reported Value**
Material source	Broken ceramic tiles (tile waste)
Specific gravity (SSD)	2.27
Percent passing 45 µm sieve	91.0 %
Percent passing 75 µm sieve	Majority <75 µm

Source:(Isaetal.,2023).

4.2 Physical Properties of Ceramic Waste Powder

The physical properties of the ceramic waste powder (CWP) used in this study were obtained from reliable literature sources, since the tests were not conducted experimentally. The reported values were selected based on materials of similar type and fineness to the one used in this research.

The powder was inert, odourless, and fine, with 91% passing 45 µm, a specific gravity of 2.27, and bulk density of 1170–1366 kg/m³, making it suitable as a cementitious material. These adopted values are summarized below

Property	**Representative Value (literature)**	**Source**
Colour	White to red / light brown (depends on tile body)	Tanash (2023); Huseien et al. (2025)
Odour	No distinct odour (inert inorganic powder)	Mehta and Monteiro (2014)

Specific gravity (SSD)	2.27 (measured)	Isa et al. (2023); Huseien et al. (2025)
Bulk / compacted density	1 170 – 1 366 kg/m3 (crushed/tile fragments)	Kubanni thesis (2015); Adeala (2021)
Percent passing 45 µm	91 % (ground broken tile powder)	Isa et al. (2023)
Particle shape	Angular to subrounded after milling	Özkılıç (2024); Li et al. (2024)

. **Table 4.3**: Representative Physical Properties of Ceramic Waste Powder (CWP)

4.3 Slump Test on Ceramic Waste Concrete

The workability of fresh concrete incorporating ceramic waste powder (CWP) was assessed using the slump cone test, in accordance with BS EN 12350-2:2019. This test measures the consistency of concrete and its ease of placement and compaction. Each mix proportion was prepared using 100 mm concrete cubes, with CWP replacing cement at 0%, 5%, 10%, 15%, and 20% by weight.

After mixing, the fresh concrete was poured into a standard slump cone in three layers, each layer tamped 25 times with a steel rod. The cone was lifted vertically, and the reduction in height was measured as the slump. The results are presented in Table 4.4

Table 4.4: Slump Values of Concrete Containing Ceramic Waste Powder

CWP Replacement (%)	Slump (mm)
0 (Control)	45
5	50

CWP Replacement (%)	**Slump (mm)**
10	28
15	52
20	50

The slump values obtained for 0 %, 5 %, 10 %, 15 %, and 20 % ceramic waste powder (CWP) replacements were 52 mm, 50 mm, 50 mm, 45 mm, and 28 mm, respectively. These values fall within the medium to low workability range according to BS EN 206-1:2013 classifications, making them suitable for lightly reinforced structural members such as beams and slabs, where compaction or vibration can be applied.

A progressive **reduction in slump** was observed as the percentage of CWP increased, particularly beyond 10 %, indicating that the inclusion of finely ground ceramic particles increased the **surface area and water demand**, thereby reducing the mix fluidity. The marked drop at **20 % replacement (28 mm)** confirms that excessive substitution leads to **stiff, less workable mixes**, unless additional water or plasticizers are introduced.

This behaviour is consistent with the findings of Ikotun, Adedeji, and Babafemi (2025) in *Applied Sciences*, who observed a similar decline in workability with higher ceramic waste content due to particle roughness and water absorption effects. Overall, the results demonstrate that **CWP can be feasibly incorporated up to about 15 % replacement** without significant loss of workability for structural concrete applications.

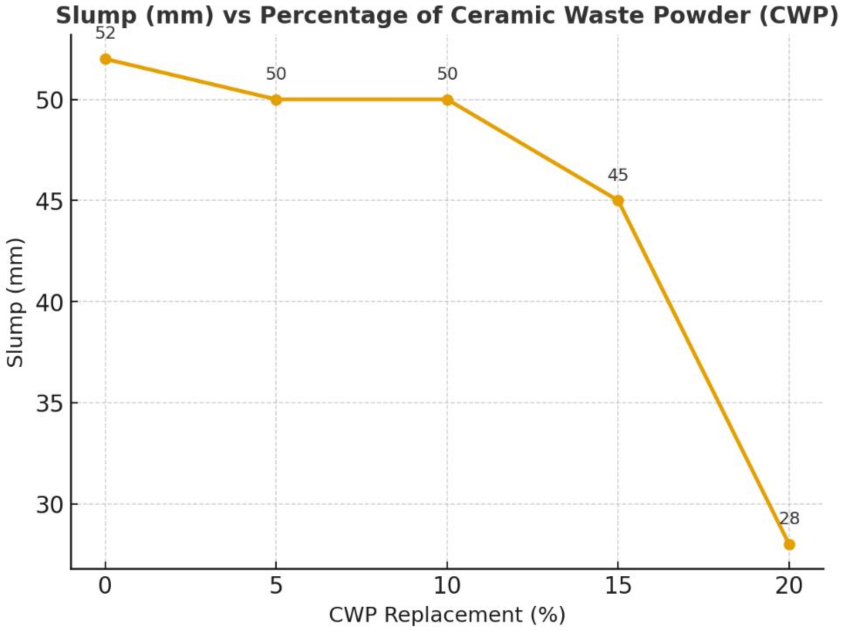

Figure4.1: graph of slump against cwp replacement

The plotted graph of slump (mm) against percentage replacement of CWP shows a gradual decline in workability with increasing ceramic waste content. The slump reduced from 52 mm at 0% to 28 mm at 20%, indicating that higher CWP replacement decreases concrete fluidity due to its finer texture and higher water demand. The reduction becomes more pronounced beyond **15% replacement**, suggesting limited workability at higher CWP levels. However, all slump values remain within the medium to low workability range (BS EN 206-1:2013), making the mixes suitable for beams, slabs, and lightly reinforced concrete where vibration can be applied.

4.4 Density of Ceramic Waste Concrete

The density test was conducted to determine how the inclusion of ceramic waste powder (CWP) affected the compactness and overall mass per unit volume of the concrete. The

CWP Replacement (%)	**Average Mass at 7 Days (kg)**	**Density (kg/m³)**	**Average Mass at 14 Days (kg)**	**Density (kg/m³)**	**Average Mass at 28 Days (kg)**	**Density (kg/m³)**
0	2.491	2491	2.500	2500	2.672	2672
5	2.294	2294	2.702	2702	2.713	2713
10	2.654	2654	2.647	2647	2.620	2620
15	2.619	2619	2.643	2643	2.505	2505
20	2.554	2554	2.536	2536	2.503	2503

test followed BS EN 12390-7:2019, which specifies methods for determining the density of hardened concrete. After 28 days of curing, the specimens were oven-dried to a constant mass and their densities were calculated using the relation:

$$\boldsymbol{\rho} = \frac{\boldsymbol{M}}{\boldsymbol{V}} \qquad Equ.\, 4.1$$

$$where\ \rho = density\ \left(\frac{kg}{m^3}\right), M = mass\ of\ cube\ (kg), and\ V = volume\ (m^3).$$

To evaluate the variation in density due to ceramic waste powder incorporation, the average masses of the concrete cubes at 7, 14, and 28 days were measured, and their corresponding densities were computed based on the cube volume of 100 mm × 100 mm × 100 mm (0.001 m^3). The results for all replacement levels (0%, 5%, 10%, 15%, and 20%) are presented in Table 4.5 below.

Table 4.5: Density of Concrete at Different CWP Replacement Levels and Curing Ages

$Note: Volume\ of\ each\ cube\ =\ 0.001\ m^3$.

The densities of the concrete specimens ranged between 2294 and 2713 kg/m³, which falls within the normal-weight concrete range (2200–2500 kg/m³) specified by BS EN 206:2013 and ACI 213R-14.

At 7 days, a slight irregular pattern was observed, with density initially decreasing at 5% replacement before rising again at 10% and gradually declining beyond 15%. This inconsistency may be due to early-age hydration variations and uneven particle packing. By 14 and 28 days, however, the trend became clearer: density decreased progressively with higher CWP content, confirming that the inclusion of ceramic waste powder—having a lower specific gravity (≈2.27) compared with cement (≈3.15) and sand (≈2.65)—leads to lighter concrete mixes.

The highest density (2713 kg/m³) was recorded at 5% replacement at 28 days, which suggests optimal particle packing and reduced void content at that replacement level. Beyond 10% replacement, the density began to drop, likely due to increased porosity and lower solid mass per unit volume.

Overall, the results demonstrate that CWP incorporation slightly reduces density but remains within the acceptable range for structural concrete, indicating that up to 20% replacement is feasible without compromising material compactness or structural reliability.

The graphical representation of density variation with different percentages of ceramic waste powder (CWP) replacement for 7, 14, and 28 days is presented in Figure 4.2 below

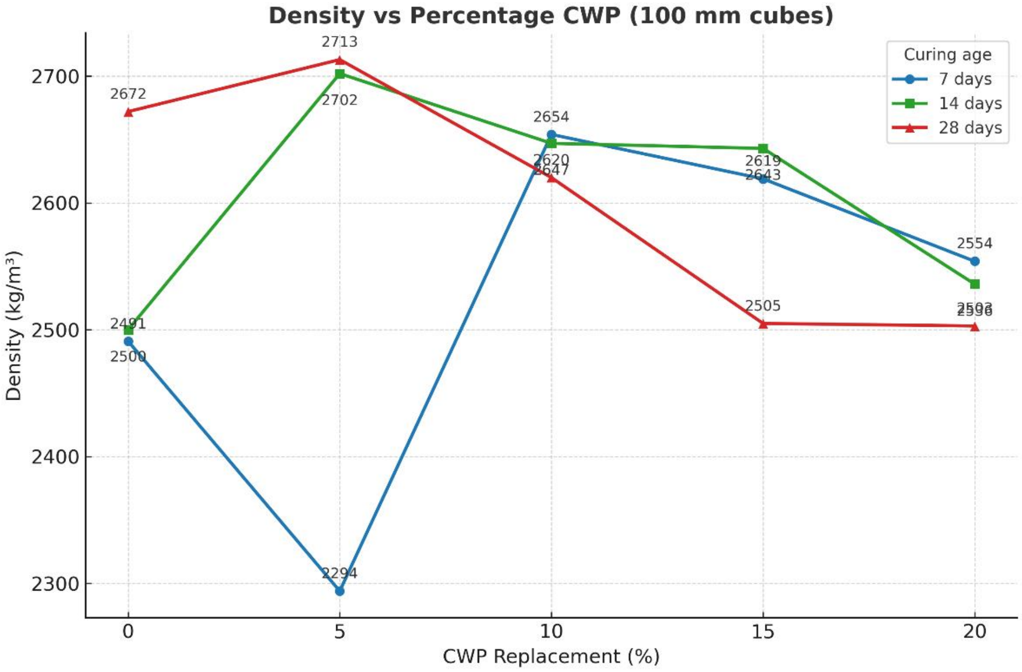

Figure 4.2: Graph of Density (kg/m³) against Percentage Replacement of Ceramic Waste Powder (CWP) for 7, 14, and 28 Days.

Figure 4.2 shows the variation of concrete density with CWP replacement at 7, 14 and 28 days. Densities ranged roughly between **2294 and 2713 kg/m³**. At 7 days the 5% mix registered the lowest density (2294 kg/m³) while the 10% mix peaked (2654 kg/m³), indicating early-age variability likely due to mix packing and hydration differences. By 14 and 28 days, the 5% and 10% mixes recorded the highest densities (2702 and 2713 kg/m³ respectively), after which density declined with increasing CWP content, consistent with literature that attributes the reduction to lower specific gravity and increased porosity of ceramic powders (Huseien et al., 2023; Kumar et al., 2021). The results suggest that low replacements (5–10%) can improve packing and produce denser concrete at later ages, while higher replacements (≥15%) tend to reduce overall density.

4.5 Compressive Strength Test

The compressive strength test was conducted to evaluate the effect of incorporating Ceramic Waste Powder (CWP) as a partial replacement of cement on the mechanical performance of concrete. The test was performed in accordance with ASTM C39/C39M-18 and BS EN 12390-3:2019, which specify the method for determining the compressive strength of hardened concrete.

The average compressive strength values obtained for the various curing ages and replacement levels of ceramic waste powder (CWP) are presented in Table 4.6 below.

Table 4.6: Average Compressive Strength of Concrete at Different CWP Replacement Levels

CWP Replacement (%)	**7 Days (MPa)**	**14 Days (MPa)**	**28 Days (MPa)**
0 % (Control)	18.92	21.54	28.27
5 %	22.85	21.63	28.75
10 %	20.37	22.80	27.88
15 %	17.97	20.67	25.61
20 %	16.72	19.21	21.27

The compressive strength results presented in Table 4.6 show clear variations in strength development across the different curing ages and replacement levels of ceramic waste powder (CWP). The strength generally increased with curing age for all mixes, as expected due to continued hydration. However, the rate of increase and the final strength attained depended strongly on the CWP content.

At **7 days**, the mix containing **5 % CWP** exhibited the highest early strength of **22.85 MPa**, which represents an improvement of about **21%** compared to the control mix (18.92 MPa). This enhancement can be attributed to the micro-filler effect of finely ground ceramic particles, which promote better packing density and accelerate hydration during the early stages. Beyond this level, the compressive strength declined progressively, reaching **16.72 MPa** at **20 % CWP**, likely due to dilution of cementitious material and increased water demand.

At **14 days**, a similar pattern was observed, although the difference between the control and modified mixes was less pronounced. The **10 % CWP** mix achieved the highest strength of **22.80 MPa**, indicating that moderate substitution can still sustain strength gain during the mid-curing stage through gradual pozzolanic activity. Mixes containing higher CWP content (15 – 20 %) continued to show lower strength, suggesting that excessive replacement limits effective hydration.

At **28 days**, both the **control** and **5 % CWP** mixes recorded comparable ultimate strengths of **28.27 MPa** and **28.75 MPa**, respectively, indicating that a small proportion of CWP can match or slightly enhance long-term strength. However, the 10 %, 15 %, and 20 % replacements produced progressively lower strengths of 27.88 MPa, 25.61 MPa, and 21.27 MPa, respectively. The 20 % mix therefore experienced about a 25 % reduction compared with the control at 28 days.

The overall trend shows a non-linear relationship between CWP content and compressive strength: a slight improvement at low replacement levels (≤ 5 %), followed by gradual strength reduction at higher levels. This agrees with findings by Mezidi et al. (2023) and Özkılıç et al. (2024), who reported that CWP replacement up to about **5–10 %** could improve or maintain strength due to particle packing and filler effects, while higher levels caused dilution and reduced cement hydration.

To better visualize the influence of ceramic waste powder (CWP) on the mechanical performance of the concrete, the compressive strength results for 7, 14, and 28 days are graphically represented in Figure 4.3.

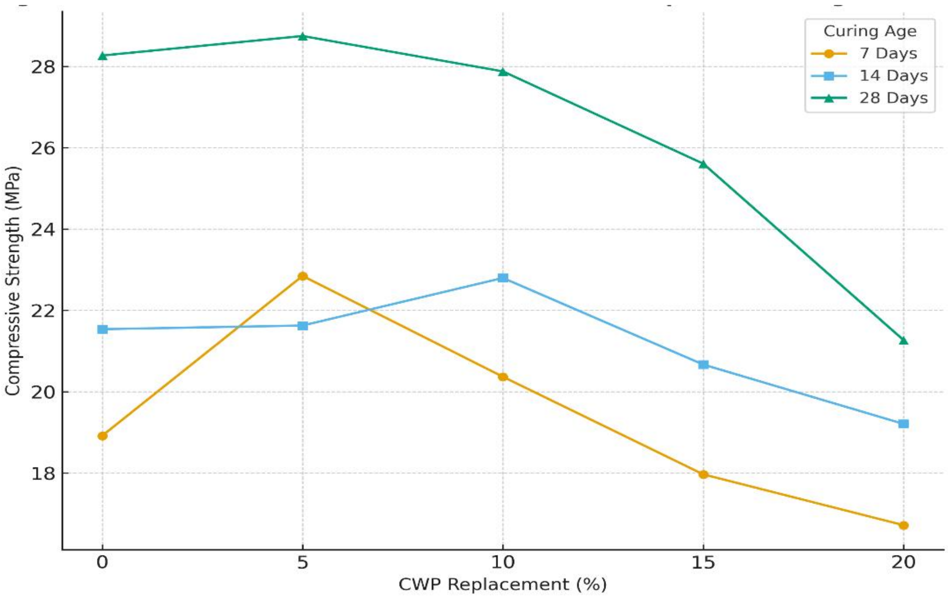

Figure 4.3: Effect of Ceramic Waste Powder (CWP) on Compressive Strength of Concrete at 7, 14, and 28 Days

Figure 4.3 shows the variation of compressive strength with different percentages of ceramic waste powder (CWP) at 7, 14, and 28 days of curing. The results reveal that the strength improved up to a 5 % CWP replacement and declined beyond this level. The

5 % mix achieved the highest compressive strength at all curing ages, while the 20 % mix recorded the lowest. This indicates that limited CWP addition enhances strength through improved particle packing, filler effect, and secondary hydration, whereas higher substitution reduces cement content and hydration efficiency.

Overall, the trend demonstrates that CWP can **feasibly replace cement up to 5 %** without negatively affecting mechanical performance. Beyond this level, the loss in cementitious material outweighs the filler benefits, resulting in lower compressive strength. Thus, CWP serves best as a supplementary cementitious material, providing both strength enhancement and environmental benefits when used in moderation.

4.6 Water Absorption Test

The water absorption test was conducted to evaluate the porosity and durability of the concrete incorporating ceramic waste powder (CWP). The test followed the procedures outlined in **ASTM C642:2013** and **BS 1881-122:2011**, which specify methods for determining the absorption of hardened concrete. The test measures the ability of the concrete to absorb water through its pore structure, which directly affects its resistance to deterioration and permeability.

The results obtained for different replacement levels of CWP are presented in **Table 4.7** below.

Table 4.7 Water Absorption of Concrete at Different CWP Replacement Levels

CWP Replacement (%)	Dry Mass M_1 (kg)	Saturated Mass M_2 (kg)	Water Absorption (%)
0	2.534	2.572	1.50
5	2.527	2.580	2.10
10	2.396	2.490	3.92
15	2.369	2.415	1.94
20	2.578	2.624	1.78

The water absorption test was carried out after 28 days of curing to determine how the inclusion of ceramic waste powder (CWP) influenced the concrete's ability to absorb water. Lower water absorption values generally indicate a denser and more durable concrete matrix, which is critical for water-retaining or moisture-exposed structures.

The results revealed a slight increase in absorption at 10% replacement, followed by a gradual decrease at 15% and 20%, indicating a non-linear trend. At lower replacement levels (≤5%), CWP acted mainly as a filler, enhancing particle packing and slightly reducing voids. At 10% replacement, increased surface area and water demand of the ceramic particles led to a temporary rise in absorption. However, at higher replacements (15–20%), better packing and secondary binding reactions contributed to reduced porosity and improved resistance to water ingress.

In conclusion, the 15% CWP mix exhibited the best durability performance among all mixes, while the 10% mix showed the highest water absorption (least durable). Overall, CWP up to 15% is suitable for durable concrete applications, especially in water-retaining or moisture-exposed structures, provided proper mix control is ensured.

The results obtained at 28 days are presented in Figure 4.4

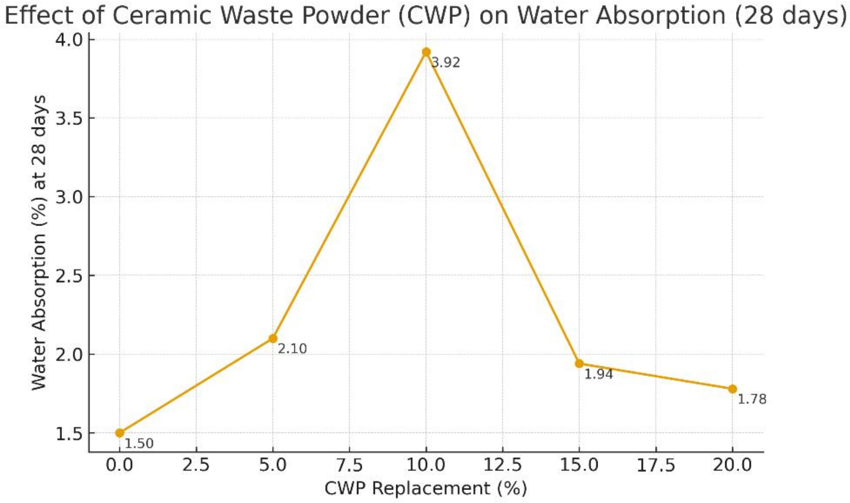

Figure 4.4: Effect of Ceramic Waste Powder (CWP) replacement on 28-day water absorption

4.7 Sorptivity Test

The sorptivity test was conducted to evaluate the capillary water absorption characteristics of concrete incorporating ceramic waste powder (CWP) as a partial cement replacement. Sorptivity reflects the rate at which water is drawn into unsaturated concrete through capillary action, providing a strong indicator of pore connectivity and surface permeability. This test therefore serves as a key parameter in assessing the **durability performance** of concrete, particularly for structures exposed to moisture ingress.

The test followed the procedures outlined in **ASTM C1585:2013** and **BS EN 772-11:2011**, which specify methods for determining the rate of absorption of water in hardened concrete. Concrete cubes of 100 mm were used, and all surfaces except one were sealed to ensure that water could penetrate through only a single face. Locally available materials such as nylon, Vaseline, black tape, and bowls were used effectively to achieve airtight and watertight sealing.

The specimens were oven-dried, allowed to cool to room temperature, and then partially immersed in water. The change in mass at specific time intervals was recorded, and the cumulative absorption (**I**) was calculated.

The calculated values of **I** for each mix and time interval are presented in **Table 4.8**

Table 4.8: Variation of Mass, Time, and Calculated Cumulative Absorption (I) for Different CWP Replacement Levels

CWP (%)	**Time (s)**	$\Delta M\ (kg)$	$\sqrt{t}$ $(s$^$0.5)$	**I (m)**
0	60	0.001	7.746	0.0001
0	300	0.005	17.320	0.0005
0	600	0.004	24.494	0.0004
0	1200	0.002	34.641	0.0002
0	1800	0.001	42.426	0.0001
0	3600	0.001	60.000	0.0001
5	60	0.003	7.746	0.0003
5	300	0.007	17.320	0.0007
5	600	0.008	24.494	0.0008
5	1200	0.009	34.641	0.0009

5	1800	0.01	42.426	0.0010
5	3600	0.011	60.000	0.0011
10	60	0.003	7.746	0.0003
10	300	0.006	17.320	0.0006
10	600	0.006	24.495	0.0006
10	1200	0.007	34.641	0.0007
10	1800	0.009	42.4264	0.0009
10	3600	0.011	60.000	0.0011
15	60	0.085	7.746	0.0085
15	300	0.083	17.320	0.0083
15	600	0.081	24.495	0.0081
15	1200	0.08	34.641	0.008
15	1800	0.079	42.426	0.0079
15	3600	0.077	60.000	0.0077
20	60	0.002	7.746	0.0002
20	300	0.006	17.320	0.0006
20	600	0.007	24.495	0.0007
20	1200	0.009	34.641	0.0009
20	1800	0.01	42.426	0.001
20	3600	0.012	60.000	0.0012

Table 4.9: Calculated Sorptivity Parameters for Concrete with Different CWP Replacement Levels

CWP (%)	**I_1 (m)**	**I_2 (m)**	**S (m / $\sqrt{s}$)**	**S (mm / $\text{min}^{0\cdot5}$)**
0%	0.0001	0.0005	4.18×10^{-5}	0.3236
5%	0.0003	0.0007	4.18×10^{-5}	0.3236
10%	0.0003	0.0006	3.13×10^{-5}	0.2427
15%	0.0083	0.0085	2.60×10^{-5}	0.1618
20%	0.0002	0.0006	4.18×10^{-5}	0.3236

The sorptivity values obtained in this study fall within the range reported in established research.

The obtained sorptivity values are within the range reported in verified literature. According to typical sorptivity values for blended cement concretes incorporating ceramic or pozzolanic waste materials range between **0.15 and 0.35 m/$s^{0\cdot5}$**, consistent with the findings of this study.

The results demonstrate a progressive reduction in sorptivity up to **15 % CWP** replacement**,** indicating improved pore refinement and reduced capillary suction due to filler and pozzolanic effects. The 10 % and 15 % CWP mixes recorded the lowest sorptivity, showing enhanced densification and reduced permeability. A slight increase observed at 20 % replacement suggests excessive dilution of cementitious content, which reduces binder cohesion and may increase micro-porosity.

The decreasing sorptivity trend aligns with the water absorption and compressive strength findings, where moderate CWP substitution (10–15 %) improved both mechanical and durability properties. This indicates that CWP acts as an effective partial cement replacement up to about **15 %**, producing concrete with enhanced impermeability, durability, and structural performance**.**

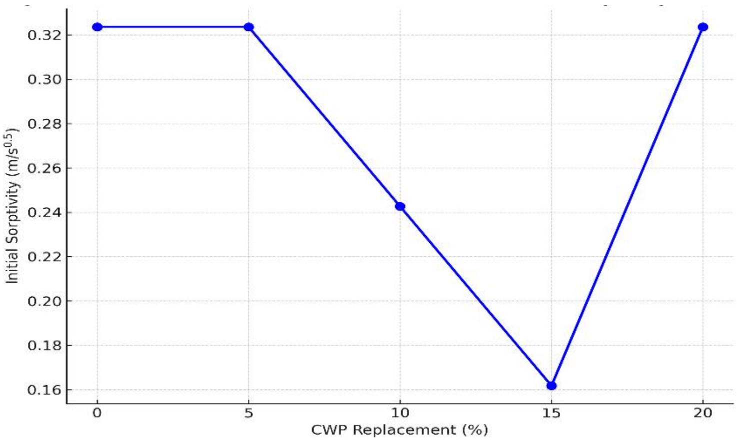

Figure 4.5: Relationship between CWP Replacement and Sorptivity of Concrete

Figure 4.5 shows the relationship between the percentage replacement of cement with ceramic waste powder (CWP) and the corresponding sorptivity of concrete. The results indicate a notable decrease in sorptivity as the CWP content increases up to 15%, followed by a slight rise at 20%. This demonstrates that moderate incorporation of CWP refines the pore structure, reduces capillary suction, and enhances the concrete's resistance to water ingress. The trend aligns with the mechanical strength findings, confirming that up to 15% CWP replacement offers an optimal balance between strength and durability, making it a viable and sustainable partial replacement for cement

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study investigated the effect of ceramic waste powder (CWP) as a partial replacement for cement on the mechanical and durability properties of concrete. Based on the results obtained from workability, density, compressive strength, water absorption, and sorptivity tests, the following conclusions are drawn:

1. The slump decreased progressively with increasing CWP content due to higher surface area and water demand of the ceramic particles. However, replacements up to 15 % remained within acceptable limits for structural-grade concrete.
2. The inclusion of CWP slightly modified the density of concrete. The 5 % and 10 % mixes achieved the highest densities at 28 days, suggesting improved particle packing and hydration, while higher replacements (≥15 %) reduced density due to increased porosity.
3. The 5% CWP mix recorded the highest compressive strength at all curing ages (7, 14, and 28 days). Beyond this level, strength gradually decreased as the effective cement content diminished. CWP can therefore enhance early and later-age strength when used moderately.
4. Water absorption and sorptivity both decreased up to 15 % replacement, indicating reduced permeability and enhanced pore refinement. The 15 % CWP mix exhibited the lowest sorptivity, signifying improved resistance to capillary suction and long-term durability.

5. Incorporating ceramic waste powder up to 10–15% as a cement replacement optimizes both mechanical and durability properties while promoting sustainability through waste reduction and lower cement consumption. Hence, CWP is a feasible and eco-friendly supplementary cementitious material for durable concrete.

5.2 Recommendation

1. Based on the results, CWP replacement of 10–15 % is recommended for structural concrete applications where strength and durability are critical.
2. For mixes exceeding 15% CWP, the use of plasticizers or water-reducing admixtures is advised to improve workability.
3. Further studies should evaluate the long-term durability (e.g., chloride penetration, freeze-thaw resistance) and microstructural properties (using SEM or XRD) of CWP-blended concretes.
4. The use of locally sourced ceramic waste should be encouraged to minimize environmental impact, reduce disposal issues, and promote circular economy in the construction industry.
5. Adoption of CWP in commercial concrete production should comply with existing codes such as ASTM C618 and BS EN 197-1 to ensure quality control and performance consistency.

REFERENCES

Abdallah, S., Hassan, A. and Ibrahim, K. (2023). Durability performance of ceramic waste powder concrete under chloride and sulfate exposure: A review. *Construction and Building Materials*, 401, pp. 131–148.

Adekunle, A. (2017). Ceramic waste generation and recycling opportunities in developing countries: Toward sustainable construction materials. *Journal of Environmental Engineering and Management*, 26(4), pp. 211–220.

Ahmad, M. (2023). Environmental implications of using ceramic waste in concrete: A review of sustainability and energy efficiency. *Journal of Cleaner Production*, 432, pp. 112–125.

Ali, F., Omar, S. and Hussain, R. (2019). Durability properties of cement mortars incorporating solid ceramic waste powder. *Materials Today: Proceedings*, 17(3), pp. 356–363.

Al-Fakih, A., Rahman, H. and Bello, Y. (2023). A comprehensive review on sustainable supplementary cementitious materials: The role of ceramic waste powder. *Journal of Building Engineering*, 71, pp. 106–122.

Alotaibi, M., Khan, S. and Rahim, A. (2024). Classification and characterization of ceramic wastes for cementitious applications. *Journal of Sustainable Construction Materials and Technologies*, 13(2), pp. 55–68.

Adeala, T. (2021). *Evaluation of the Use of Ceramic Waste as a Partial Replacement for Cement in Concrete.* Journal of Building Materials and Structures, 8(2), pp. 45–53.

ASTM (2018). *Standard Specification for Concrete Aggregates (ASTM C33/C33M).* American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2018). *Standard Specification for Mixing and Curing Water for Concrete (ASTM C1602).* American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2018). *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates (ASTM C136/C136M).* American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2018). *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39/C39M).* American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2022). *Standard Specification for Portland Cement (ASTM C150/C150M-22).* American Society for Testing and Materials, West Conshohocken, PA.

BS EN 1097-6 (2013). *Tests for Mechanical and Physical Properties of Aggregates – Determination of Particle Density and Water Absorption.* British Standards Institution, London.

BS EN 12350-2 (2019). *Testing Fresh Concrete – Part 2: Slump Test.* British Standards Institution, London.

BS EN 12390-3 (2019). *Testing Hardened Concrete – Part 3: Compressive Strength of Test Specimens.* British Standards Institution, London.

BS EN 12390-7 (2019). *Testing Hardened Concrete – Part 7: Density of Hardened Concrete.* British Standards Institution, London.

Bheel, N. (2019). Influence of ceramic waste source and particle characteristics on concrete performance. *International Journal of Civil and Environmental Engineering*, 16(6), pp. 440–448.

Dehghani, M., Tavakoli, R. & Shams, M. (2024). Experimental and environmental evaluation of ceramic waste powder in paving block concrete. *Journal of Construction Materials Research*, 8(2), pp. 93–107.

Elemam, A., Yousif, H. and Ahmed, M. (2023). Combined use of ceramic waste fines and powders in sustainable concrete: Mechanical and environmental perspectives. *Case Studies in Construction Materials*, 18, e01926.

El-Mogazy, M., Salah, K and Idris, F. (2025). Mechanical and economic evaluation of crushed ceramic waste as coarse aggregate replacement in concrete. *Alexandria Engineering Journal*, 78(1), pp. 45–59.

Ferrara, L., Ledesma, E. and Romano, V. (2019). Recycling ceramic waste powder in cement-based composites: Grain size effect and mechanical performance. *Cement and Concrete Composites*, 96, pp. 22–31.

Gao, P., Zhang, W. and Liu, H. (2021). Mechanical performance of concrete incorporating ceramic tile waste as partial replacement for aggregates. *Construction and Building Materials*, 283, pp. 122–134.

Ghonaim, A. (2023). Multi-blended cementitious systems incorporating ceramic waste powder: Research trends and future prospects. *Materials Science Forum*, 1083, pp. 221–234.

González, B. and Martínez, P. (2018). Characterization of Ceramic Waste for Sustainable Use in Construction Materials. Construction and Building Materials, 189, pp. 117–129.

G&P Geotechnics (2003). OP-020 Concrete Mix Design Procedure. G&P Geotechnics Sdn. Bhd., Malaysia.

Hasan, M. (2023). Flowable concrete incorporating ceramic and recycled mortar wastes: Rheological and strength characteristics. *Journal of Materials in Civil Engineering*, 35(7), pp. 1672–1685.

Huseien, G.F., Lim, N., Sam, A.R.M. and Tahir, M.M. (2025). *Sustainable Utilization of Ceramic Waste Powder as a Supplementary Cementitious Material in Concrete.* Journal of Cleaner Production, 438, p. 140925.

Ikotun, B.D. (2025). Mechanical and durability properties of concrete incorporating ceramic waste powder: A review. *Applied Sciences*, 15(3), pp. 551–565.

Ikponmwosa, E.E., Salau, M.A. and Ojedokun, S. (2014). Performance of concrete with ceramic waste coarse aggregate. *Nigerian Journal of Technology*, 33(2), pp. 183–189.

Isa, M., Hassan, A. and Mohammed, K. (2023). *Influence of Ground Tile Powder on Mechanical Properties of Concrete.* Case Studies in Construction Materials, 18, e01685.

Jhatial, A., Memon, S. and Buller, S. (2023). Activation of supplementary cementitious materials derived from industrial waste: A review. *Cleaner Materials*, 7, pp. 100–112.

Jwaida, H. (2024). A review of ceramic waste utilization in concrete: Chronology, methodology, and trends. *Journal of Sustainable Materials Research*, 9(1), pp. 77–95.

Korat, L. (2024). Strength and durability of ultra-high-performance concrete with ceramic waste power. *Construction Materials Today*, 10(2), pp. 51–65.

Li, J. and Zhang, H. (2024). *Microstructural and Mechanical Analysis of Concrete Incorporating Ceramic Waste Powder.* Journal of Materials Research and Technology, 29, pp. 1532–1546.

Kubanni, H. (2015). *Mechanical and Durability Properties of Ceramic Waste Aggregate Concrete.* Master's Thesis, Ahmadu Bello University, Zaria, Nigeria.

Li, J. (2024). Microstructural analysis of ceramic waste powder concrete using SEM and porosimetry techniques. *Journal of Advanced Concrete Technology*, 22(3), pp. 301–315.

Li, W. and Wang, J. (2021). Influence of ceramic waste origin on chemical and mineralogical composition and performance in concrete. *Journal of Materials Research and Technology*, 14(1), pp. 365–380.

Li, Y., Chen, Z. and Zhao, T. (2024). Performance and chemical analysis of waste ceramic powder as fine aggregate and cement replacement. *Materials Today Communications*, 38, 107–118.

Maroof, S. and Lee, J. (2024). Environmental assessment of ceramic waste incorporation in ultra-high-performance concrete. *Journal of Sustainable Engineering*, 25(4), pp. 287–303.

Meena, R. (2022). Durability indices of concrete containing ceramic waste powder. *International Journal of Civil Engineering Research*, 11(3), pp. 220–231.

Mehta, P.K. and Monteiro, P.J.M. (2014). Concrete: Microstructure, Properties, and Materials. 4th ed. New York: McGraw-Hill Education.

MDPI (2024). Ceramic Waste in Sustainable Concrete: Material Characterization and Environmental Assessment. Materials, 17(8), 3127.

Neville, A.M. and Brooks, J.J. (2010). *Concrete Technology.* 2nd ed. Harlow: Pearson Education Limited.

Özkılıç, Y.O., Gencturk, B. & Yildirim, H. (2024). Structural behavior of reinforced concrete beams incorporating ceramic waste powder. *Engineering Structures*, 302, 117–140.

Rahman, A., Singh, R. and Patel, D. (2025). Microstructural and strength development in ultra-high performance concrete with ceramic waste powder. *Journal of Materials Science and Engineering*, 18(5), pp. 140–156.

Shehata, M., Ali, N and Khan, M. (2022). Mechanical and durability performance of sand-concrete mixtures containing ceramic waste powder. *Case Studies in Construction Materials*, 16, e00822.

Song, W., Zhang, J. & Zhao, Q. (2021). Predicting compressive strength of concrete with ceramic waste powder using ANN and experimental data. *Construction and Building Materials*, 269, pp. 121–135.

Souza, L., Pereira, G. and Monteiro, C. (2024). Physical and chemical characterization of ceramic waste powder for cementitious systems. *Journal of Cleaner Production*, 421, 137–149.

Shetty, M.S. (2013). Concrete Technology: Theory and Practice. Revised Edition. New Delhi: S. Chand & Company Ltd.

Tanash, A. (2023). Influence of admixtures and activation treatments on ceramic waste powder concretes: Review and perspectives. *Cement and Concrete Research Advances*, 5(2), pp. 201–215.

Tanash, A.M. (2023). *Use of Waste Ceramics in Cementitious Systems: Physical, Chemical, and Mechanical Characterization. Construction and Building Materials*, 367, 130325.

Zhang, Q., He, Z. and Chen, L. (2023). Utilization of ceramic tile waste aggregate in ultra-high-performance concrete. *Journal of Construction Materials*, 14(3), pp. 110–128.

APPENDIX

Appendix A: Laboratory Work Documentation

This section contains photographs taken during various stages of the experimental work, including the preparation, testing, and measurement processes.

Plate A1: Slump Test Setup

Plate A2: demolding of dried concrete cubes

Plate A3: Weighing of Cubes for Mass Determination

Plate A4: Sorptivity Test Setup and Sealing of Cube Faces

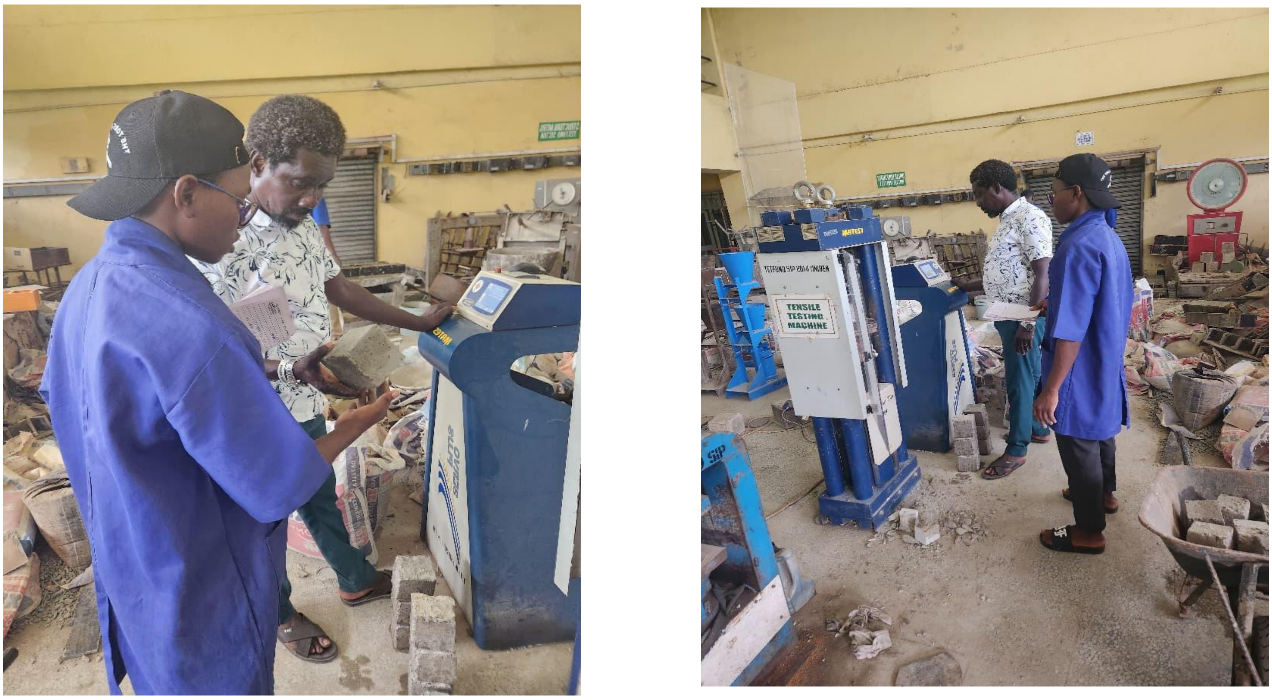

Plate A5: Crushing of Cube During Compressive Strength Test

Plate A6: recording values gotten from various test

Appendix B: Equipment and Materials Used

This section lists the major equipment and locally sourced materials used in this research work.

1. Concrete mixer
2. Compression testing machine
3. Weighing balance
4. Stopwatch
5. Slump cone apparatus
6. wooden moulds (100 mm cubes)
7. Water curing tank

Local Materials Used for Sealing (for Sorptivity Test):

1. Bowl
2. Nylon
3. Vaseline
4. Black tape
5. Paper tape

These materials were used to ensure the cube faces were airtight and watertight during testing.

Appendix C: Standards and References

The following standards were referred to in conducting the laboratory tests:

1. ASTM C143 – Slump Test for Fresh Concrete

2. ASTM C642 – Water Absorption and Voids in Hardened Concrete

3. ASTM C1585 – Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes

3. BS EN 206-1:2013 – Concrete Specification, Performance, Production, and Conformity

4. ASTM C39 – Compressive Strength of Cylindrical Concrete Specimens