Investigation of Ceramic Tile Waste as Partial Replacement of Cement in concrete

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Civil Engineering (Construction Technology and Management)

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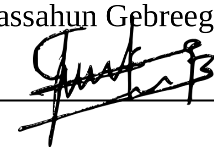
Dedication

This research work is dedicated to my beloved mother Birhan Hiluf and my dear sister Meron Kassahun. Your unwavering support, endless encouragement and boundless love have been my guiding light throughout this journey.

Declaration

I, the undersigned, declare that this thesis work entitled "Investigation of Ceramic Tile Waste as Partial Replacement of Cement in concrete" is my original work and has not been presented to any other university for the similar or other degree award. That all sources of material used for the thesis have been duly referenced and acknowledged.

Tsegay Kassahun Gebreegzabiher



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Abstract

The construction industry's rapid growth coupled with increasing environmental concerns and necessitates sustainable practices. The study investigates grinded ceramic tile wastes as a partial replacement for cement for C-30 concrete grade having an aim to feel material scarcity and enhance sustainability in the construction industry.

After the concrete ingredients test, mix design of C-30 concrete grade was prepared and concrete cube specimen with 0%, 5%, 10%, 15%, 20%, 25% and 30% of ceramic tile wastes in place of cement were casted, cured and tested for compressive and flexural strength.

The experimental test results have revealed, an increase in the proportion of grinded ceramic tile waste in concrete production decreases workability. In terms of strength, both compressive and flexural strengths initially increased with ceramic tile waste, peaking at 10% replacement with a compressive strength of 40.26 MPa and a flexural strength of 4.31 MPa at 28 days. Beyond 10%, both strengths declined indicating that while moderate ceramic waste enhances concrete strength but excessive replacement negatively impacts performance. And the cost analysis revealed that incorporating ceramic waste significantly reduces the cement cost.

It can therefore be concluded that in areas where cement scarcity or high costs are prevalent, the partial replacement of cement with grinded ceramic tile waste in concrete is a viable and sustainable alternative. The use of ceramic waste at optimal levels can improve strength properties and offers significant cost advantages while contributing to waste management and reducing the environmental impact of construction activities.

Key-words: Ceramic tile wastes, Workability, Compressive strength, Flexural strength, concrete

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List of Symbols and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ASTM	American Society for Testing Materials
Al_2O_3	Dialuminuim Trioxide
BS	British Standard
C&D	Construction and Demolition
C_2S	Tricalcium Silicate
C_2S	Dicalcium Silicate
C_2A	Tricalcium Aluminate
C_2AF	Tetra calcium Alumino Ferite
CaO	Calcium Oxide
$CaCl_2$	Calcium chloride
Cm^2/g	Centimeter square per gram
EC	Ethiopian Calendar
EN	Euro Norm
Fe_2O_3	Iron Oxide
g	Gram
IS	Indian Standard
Kg	Kilo gram
KN	Kilo Newton
MC	Mix Code
MgO	Magnesium Oxide
Mn_2O_3	Manganese Oxide

m	Meter
mm	Millimeter
m^3	Cubic Meter
m^2	Square Meter
MPa	Mega Pascal
OPC	Ordinary Portland Cement
P.L.C	Private Limited Company
P_2O_5	Diphosphorus Pentaoxide
SO_3	Sulpher Trioxide
SiO_2	Silicon Dioxide
SRPC	Sulphate Resisting Portland Cement
UAE	United Arab Emirates
w/c	Water Cement Ratio
%	Percentage

Chapter 1: Introduction

1.1 General Background

The construction industry is constantly exploring sustainable practices to reduce its environmental impact, and one such practice is the utilization of construction and industrial waste materials in concrete production. The incorporation of ceramic waste tiles as a partial replacement for cement in concrete is a promising approach that aligns with the principles of sustainable development.

Ceramic waste, particularly from construction site and tile manufacturing, constitutes a significant portion of industrial waste. Disposal of this waste in landfills not only occupies valuable land but also poses environmental hazards due to its non-biodegradable nature. Therefore, finding an alternative use for ceramic waste is crucial for environmental conservation.

Construction and Demolition (C&D) wastes contribute the highest percentage of wastes world-wide (75%). Furthermore, ceramic materials contribute highest percentage of wastes within the C&D wastes. The current option for disposal of ceramic wastes is land-fill. This is due to unavailability of standards, avoidance of risk, lack of knowledge and experience in using ceramic wastes in construction. The ability of ceramic wastes to act as a pozzolanic material in the production of cement has been effectively explored [1].

In Ethiopia ceramic wastes are a problematic material in its substances. In our society wastage of ceramic tiles disposed as landfill. However, using ceramic wastes, as landfill may not be the best option, depending on whether there can be leaching of chemicals that can be detrimental to the environment. This also negates the concept of sustainable development, and hence the need to investigate alternative beneficial use of these wastes.

Therefore, this research aimed to investigate some benefits which are obtained by the use of ceramic tile waste powder as a construction material. In order to show the effects of ceramic tile waste powder on concrete properties, such as: workability, and strength, laboratory experimentations were performed by adding dosages of 0%, 5%, 10%, 15%, 20%, 25% and 30% ceramic tile waste powder in concrete mixes and results are conducted. Then, based on the experimental results conclusion are drawn and recommendations are forwarded.

1.2 Problem Statement

The construction industry in Ethiopia is experiencing rapid growth driven by urbanization and infrastructural development [2]. However, this growth has led to increased demand for construction materials particularly cement which faces a shortage of supply and its high cost. In addition to this, The construction industry generates substantial amounts of ceramic tile waste which is typically disposed in landfills leading to waste management issues and increasing environmental pollution.

Understanding the effects of ceramic waste tile on concrete properties is crucial for promoting sustainable construction practices in Ethiopia. This study aims to address the gap by investigating the mechanical properties of concrete incorporating ceramic waste tile as a partial replacement for cement.

1.3 General Objective

The general objective of this research is to investigate grinded ceramic tile wastes as a partial replacement of cement in concrete production.

1.4 Specific Objectives

1. To investigate the workability of concrete when cement is partially replaced with different proportions of grinded ceramic tile wastes.
2. To investigate the comprehensive strength of concrete produced by partially replacing cement with different proportions of grinded ceramic tile wastes.
3. To investigate the flexural strength of concrete produced by partially replacing cement with different proportions of grinded ceramic tile wastes.
4. To carry out the cost comparison for concrete produced using different proportion of grinded ceramic tile wastes as partial replacement of cement.

1.5 Scope of the Study

The main focus of this research is to study the effects of ceramic tile waste powder in C-30 concrete grade by adding dosages of 0%, 5%, 10%, 15%, 20%, 25% and 30% ceramic tile waste powder in the concrete mixes. the research encompasses concrete mix design, experimental testing of mechanical properties including compressive strength and flexural strength. Comparative studies between ceramic waste tile-incorporated concrete and usual concrete will be conducted to evaluate benefits, drawbacks, and practical applicability in construction projects.

The findings aim to provide valuable insights and recommendations for promoting sustainable concrete production practices.

1.6 Organization of the Study

This research paper contains five chapters: Chapter (1) deals with introduction of the research; Chapter (2) deals with extensive literature Reviews; Chapter (3) deals with methodology; Chapter (4) deals with result and discussion; Chapter (5) deals with conclusions and recommendations. At the last but not least, the references and appendices are included.

Chapter 2: Literature Review

2.1 Concrete

Concrete is a composite material prepared by mixing cement, supplementary cementing materials, aggregates, water, and chemical admixtures in suitable proportions, and allowing the resulting mixture to set and harden over time. To produce high quality concrete, choosing appropriate constituent materials for a particular concrete is necessary, but not sufficient condition. Because, the materials must be proportioned correctly, and the concrete must then be mixed, placed, and cured properly [3].

Concrete should be workable, easy to finish, strong, durable, watertight, and wear resistant. These qualities can often be obtained easily and economically by the selection of suitable materials rather than by adding admixtures [4]. Admixtures are added in special cases to maintain the quality of concrete. Therefore, in order to achieve the desired property of concrete evaluation and investigation of ingredients behavior is primary and necessary activity.

2.1.1 Concrete Properties

Properties of concrete are highly dependent on the properties of its ingredients and the properties of fresh concrete may also affect the property of hardened concert. Workability, strength and durability are properties that make concrete the most versatile and extensively used construction material over the world.

2.1.1.1 Workability

Workability is a property which determines the ease and homogeneity of fresh concrete or mortar, that the concrete could be mixed, placed, consolidated and finished [5]. Consistency is a property of concrete considered a close indication of workability [6]. The consistency of concrete mainly depends on water to cement ratio, aggregate to cement ratio and water amount.

When the aggregate to cement ratio is reduced in concrete production, the water content must increase for the water to cement ratio to remain constant. The increase in fine aggregate to coarse aggregate ratio generally increases the water content required to produce a given workability. Lowering the cement content of concrete with given water content typically will increase workability. Increase in cement fineness decreases workability and high fineness will cause a concrete mixture to lose workability more rapidly because of its rapid hydration [7].

Workability of concrete could be measured qualitatively by observing its flow ability, compact ability and pump ability, or quantitatively by using Slump test, Compact factor, vebe test and flow table. Among those methods Slump test is simple, quick and most universally used to measure workability [4].

The test results obtained from slump test are true slump, zero slump, shear slump and collapsed slump. If the slumping occurs evenly all around, it is true slump. Mixes with very stiff consistency have zero slump. If one-half of the concrete slides down along an inclined plane, it is regarded as shear slump. This indicates that insufficient cohesiveness and the concrete proportions should be adjusted. Mixes with non-uniform distribution of aggregates or very workable mix may collapse [4]. Table 2.1 summarizes the methods for measuring workability of concrete their respective code of standard.

Table 2.1 Methods for measuring workability of concrete [4]

S. No.	*Test name*	*Code*
1.	Slump test	ASTM C 143 [8], EN 12350 [9], BS 1881 Part 102 [10]
2.	Compacting factor test	BS 1881 Part 103 [11]
3.	Vebe test	BS 1881 Part 104 [12], EN 12350 [13]
4.	Flow table test	BS 1881 Part 105 [14], EN 12350 [13]

2.1.1.2 Compressive Strength

The compressive strength of concrete is a fundamental physical property frequently used in design calculations for bridges, buildings, and other structures. It is the measured maximum resistance of a concrete specimen to axial loading at the age of 28 days [6]. Although most common compressive strength test is taken at age of 28 days, additional test can be made at 3, 7 and less commonly 1, 2 and 14 days, 13 and 26 weeks and 1 year [15].

The compressive strength of concrete is determined using small specimens. However, the strength of a given concrete specimen is influenced by several secondary factors such as the rate of loading, moisture condition, specimen size and curing condition. According to BS EN 12390-1:2000, the test cubes are casted in molds of prescribed dimensions such as 50 mm, 100mm or 150m. The cube dimensions are selected depending on the aggregate size, the filling, compaction and curing conditions [15]. The compressive strength of concrete is highly dependent on the water to cement ratio that strength increase as the w/c ratios decrease.

2.1.1.3 Flexural strength

Flexural strength also known as the modulus of rupture, is a measure of an unreinforced concrete beam or slab's ability to resist failure in bending. It is a critical property in concrete, particularly for structures like beams, slabs, and pavements. understanding flexural strength is essential for designing structures that can withstand bending forces without cracking or breaking [6].

The most common method for testing flexural strength is the third-point loading test (ASTM C78 [16]) or center-point loading test (ASTM C293 [17]). Typically, standard beam specimens with dimensions of 150 mm x 150 mm x 500 mm are used for testing. The testing is often conducted at 7, 14, and 28 days to capture the development of strength over time, with 28 days being the most common age for final assessment. Various factors, including the water-cement ratio, aggregate type, and curing conditions, significantly influence the results. Studies have shown that materials like fibers, nano-silica, and partial cement replacements, such as ceramic tile waste, can enhance flexural strength, making the concrete more resilient to cracking and bending failures [15].

2.1.1.4 Durability

Durability of concrete is defined as the ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration to maintain its original form, quality, and serviceability when exposed to its intended service environment [18].

Permeability of concrete is a function of durability. Although there are no prescribed permeability tests by ASTM and EN standards, it could be measured by applying water under pressure to the top surface of specimens and the coefficient of permeability would be calculated in laboratory [7].

2.1.2 Concrete Ingredients

For special purposes, different additives could be added to concrete mixes, but the common ingredients of concrete are cement, aggregates (fine and coarse), water and admixtures. On this section, only those four basic ingredients and their properties are described. Cement acts as the binding agent, reacting chemically with water through hydration to form a paste that hardens and binds the aggregates together. Aggregates, which make up the bulk of the concrete, provide compressive strength and volume stability. The water-to-cement ratio is critical in determining the workability, strength, and durability of the concrete.

2.1.2.1 Cement

Cement is a hydraulic binder and finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes which, after hardening retains its strength and stability even under water [19].

Portland cement is the most popular and widely used building material, due to the availability of the basic raw materials all over the world, and its ease of use in preparing and fabricating all sorts of shapes [20].

In Ethiopia, Ordinary Portland cement, Portland pozzolana cement, rapid hardening Portland cement, low heat Portland cement and sulfate resisting Portland cement are the most common types of hydraulic cement. Among those, ordinary Portland cement is extensively used in concrete construction. It is more suitable than other cements, for use in general concrete construction where there is no exposure to sulfates in the soil or in ground water.

I. Composition of Portland cement

Portland cement consists of four major minerals and other minor constituents. The four major minerals of Portland cement are Tricalcium Silicate (C_3S), Dicalcium Silicate (C_2S), Tricalcium Aluminate (C_3A), Tetracalcium Aluminoferrite (C_4AF). C_4AF gives color to the cement, C_3S use for early strength, C_2S use for late strength, C_3A use for hydration of cement paste. The minor components found on Portland cement are Mn_2O_3, P_2O_5, TiO_2 and MgO etc. Silicate mineral's which are largely responsible for the strength development and the long-term structural and durability properties of Portland cement. The minor constituents also, have to be controlled on account of their impact on cement properties and also durability [4].

The reason for strength of concrete is hydration reaction. The hydration of Portland cement involves the reaction of the calcium silicates and aluminates with water to form hydrated phases. The calcium silicate hydrate gel is the main glue which binds the sand and aggregate particles together in concrete. The water to cement ratio determines workability and compressive strength of concrete. As the water to cement ratio in original mix increases the, workability also increases the compressive strength rather decreases down [4].

The cement use for study is ordinary Portland cement produced by Messobo cement factory. The oxide composition of Messebo OPC cement presented on the Table 2.2.

Table 2.2 Oxide composition of Messebo ordinary Portland cement [7]

S. No.	*Oxide Composition*	*Percentage by weight (%)*
1.	CaO	63.94
2.	SiO_2	20.50
3.	Al_2O_3	4.75
4.	Fe_2O_3	3.70
5.	MgO	1.31
6.	SO_3	2.41

II. Physical properties of Portland cement

Fineness, normal consistency, setting time, soundness and strength are the common physical properties of cement. But in this portion, only normal consistency and setting time reviewed in detail.

i. Normal consistency

In order to determine initial setting time, final setting time and soundness tests, neat cement paste of standard consistence has to be used. Therefore, for any given cement, it's necessary to determine the water content which will produce a paste of standard consistency [15].

According to ASTM C 187 [21], the normal consistency of cement paste is determined by using Vicat apparatus. The apparatus shall be of normal consistency when the standard 10mm plunger settles to a point 9-11mm below the original surface in 30s after being released. The water content required for standard consistency is from 23%-33% by weight of cement.

ii. Setting time

The term setting refers to the solidification of the plastic cement paste. The cement paste also requires considerable time to become fully rigid. The beginning of solidification and is called initial set and the time taken to solidify completely called final set. The most commonly used methods for determination of initial and the final setting times are Vicat and Gillmore needle tests [18].

The initial setting time is determined when the 1mm vicat needle penetrates 25mm to the standard cement paste. But the final setting time is determined by replacing 1mm needle by needle with annular attachment and when the needle fails to make impress on standard cement paste. In most cases, Initial set usually occurs within 2 to 4 hours, while final set takes 5 to 8 hours after initial water-cement contact. The initial and final setting time measuring by vicat apparatus have different requirements as presented in the Table 2.3. and the physical properties of cement are highly dependent on the chemical composition of cement and several standards of cement as summarized in the Table 2.4.

Table 2.3 Setting time requirement for Portland cement

S. No.	*Code of standard*	*Cement type*	*Setting time*	
			Initial (min), Not less than	*Final (min), Not more than*
1.	ASTM C 150 [22]	All types	30	375
2.	IS 8112 [23]	OPC	30	600
	IS 1489	PPC		
3.	BS EN 196	All types	60, for 32.5N, 32.5R, 42.5N and 42.5R Strength classes45	-
4.	ES 11763	All types	45	600

Table 2.4 Physical properties of Portland cement

S. No.	*Property*	*Test name*	*Code*
1.	Fineness	Blaine air-permeability test	ASTM C 204 [24]
		Wagner turbid meter test	ASTM C 115 [25]
		Fineness by No. 3259(45µm)	ASTM C 430 [26]
2.	Normal consistency	Vicat plunger	ASTM C187 [27]
		Flow Table	ASTM C1437 [28]
3.	Setting Time	Vicat apparatus	ASTM C191 [29]
		Gillmore Needles	ASTM C 266 [30]
4.	Soundness	Autoclave Expansion	ASTM C151 [31]
5.	Strength	Compressive strength test	ASTM C109 Mortar cubes [32] ASTM C 349 Mortar prisms [33]
		Flexural strength test	ASTM C 348 [34]

2.1.2.2 Aggregates

Aggregates are the important constituents in concrete that give body to the concrete, reduce shrinkage and effect economy. 70-80% volume of concrete is occupied by both fine and coarse aggregates. They are inert granular materials such as sand, gravel or crushed rocks, and are mixed with water and cement to create concrete which is hard, strong and long lasting [35].

Aggregates are not always truly inert materials, because of the physical, thermal and chemical properties of aggregates influence the performance of concrete. There are properties directly affected by the property of parent rock such as strength, hardness, mineral composition, specific gravity, color etc. However, properties such as particle shape, particle size, surface texture and absorption are not affected by the property of parent rock. Those properties of aggregates have considerable effect on fresh and hardened concrete performance [36].

I. Physical properties of Aggregates

During selection of aggregates for concrete production, not all properties of aggregate are considered. The properties which are considered for selection are grading, shape, texture, specific gravity, bulk density, voids, porosity, moisture content, bulking and strength [37]. The properties of aggregate significantly affect the resulting concrete quality explained briefly under this section.

i. Gradation

Gradation is the grain size distribution of particles of granular materials. The main reasons for specifying grading limits and maximum aggregate size are their influence on workability and economy. Very coarse sands produce harsh and unworkable concrete material, however very fine sands increase the water requirement consequently increase cement requirement which makes it uneconomical. The maximum size of aggregate is conventionally designated by the sieve size on which fifteen percent or more particles are retained [38]. ASTM C 33 [40] and ES 81:2001 [38] Specified aggregates grading requirements.

Table 2.5 Grading requirements for coarse aggregate [38]

Nominal size of graded aggregate mm	Percentage Passing through test sieves having square opening						
	75 mm	63 mm	37 mm	19 mm	13.2 mm	9.5mm	4.75mm
38-5	100		95-100	30-70		10-35	0-5
19-5			100	95-100		25-55	0-10
13-5				100	90-100	40-85	0-10

Table 2.6 Grading requirements for fine aggregate [38]

S. No.	*Sieve size*	*Percentage passing*
1.	9.5 mm	100
2.	4.75 mm	95-100
3.	2.36 mm	80-100
4.	1.18 mm	50-85
5.	600 µm	25-60
6.	300 µm	10-30
7.	150 µm	2-10

ii. Fineness Modulus

The fineness modulus is calculated from sieve analysis data by adding the cumulative percentages of aggregate retained on each of a specified series of sieves divided by 100. The sieves used for determining the fineness modulus are150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, 4.75 mm, 9.5 mm, 19 mm, 37.5 and larger, increasing in the ratio of 2 to 1. The higher the fineness modulus is the coarser the aggregates. Fineness modulus of fine aggregate is useful in estimating proportions of fine and coarse aggregates in concrete mixtures production [18].

iii. Specific Gravity

The specific gravity of an aggregate is the ratio of its mass to the mass of an equal volume of water. Most natural aggregates have specific gravity between 2.40 and 2.90, which indicates aggregates are 2.40 to 2.90 times denser than water. Methods for determining relative densities for coarse and fine aggregates are described in ASTM C 127 [7].

iv. Unit Weight

The unit weight of an aggregate is the mass or of aggregate required to fill a container of a specified unit volume. The approximate unit weight of aggregate commonly used for normal-weight concrete ranges from 1200 kg/m3 to 1750 kg/m3. The methods used to determine the unit weight of aggregate are prescribed in ASTM C 29 [6].

v. Water Absorption and Moisture Content

The internal structure of an aggregate particle is made up of solid matter and voids that may or may not contain water. So, the total water content of the concrete can be controlled and correct batch weights determined. Generally, coarse and fine aggregates have percentage water absorption in the range of 0.2% to 4% and 0.2% to 2% respectively. The absorption capacity and surface moisture of aggregates should be determined according to ASTM C70, ASTM C127, ASTM C128, and ASTM C566 [36].

vi. Silt Content

Materials that pass through 75-μm sieve openings form a coating on the aggregate particle and weaken the bond between cement paste and aggregate. When the finer materials are present in excessive amounts, the water requirement of the concrete mixes increases significantly. Consequently, there would be reduction in strength. The Ethiopian standard recommends washing the fine aggregate if the silt content exceeds a value of 6% by mass [39]. Some selective properties of aggregate are summarized in the table 2.7.

Table 2.7 Properties of Aggregates

S. No.	*Property*	*Test name*	*Code*
1.	Aggregate gradation	Sieve analysis	ASTM C136 [41]
2.	Specific gravity	Specific gravity for FA	ASTM C127 [42]
		Specific gravity for CA	ASTM C128 [43]
3.	Absorption capacity	Absorption capacity for Aggregates	ASTM C70 [44]
4.	Moisture content	Moisture Content	-
5.	Unit weight of CA	Unit weight	ASTM C29 [45]
6.	Silt content	Silt content	-

2.1.2.3 Water

In general, the water used for drinking purpose and has no pronounced odor and test could be used as mixing water in concrete production. However, the water not suitable for drinking purpose should be qualified by requirements stated in ASTM C1602 to be used as ingredient of concrete [6].

2.2 Ceramic

Ceramic materials are inorganic, non-metallic solids that are typically produced by the heating and subsequent cooling of natural minerals, such as clay. They are characterized by their hardness, brittleness, high melting points, and resistance to chemical erosion and heat. Ceramics are widely used in various applications, including construction, electronics, and household items, due to their durability and insulating properties. In construction, ceramics are commonly used as tiles, bricks, and sanitary ware, offering aesthetic appeal and long-lasting performance. Technological advancements have also led to the development of advanced ceramics, which are used in high-tech applications such as aerospace, medical devices, and electronics, where they provide excellent wear resistance, thermal stability, and mechanical strength. The environmental sustainability of ceramics is also notable, as they can be produced from abundant natural resources and are often recyclable. [46].

2.2.1 Composition and Properties of Ceramic Waste

Ceramic waste is predominantly composed of silica (SiO_2), alumina (Al_2O_3), and other oxides such as iron oxide (Fe_2O_3) and calcium oxide (CaO). These materials contribute to the high compressive strength and durability. The physical properties of ceramic waste such as surface area and pozzolanic activity are critical factors that influence its potential applications [47].

I. Chemical Composition

The high silica and alumina content in ceramic waste makes it similar to natural pozzolanic materials, which can react with calcium hydroxide in the presence of water to form compounds possessing cementitious properties [47].

Table 2.8 Chemical properties of ceramic waste and Messebo OPC cement [7], [48]

S. No.	Materials	Oxide Composition (%)	Messebo OPC Oxide Composition
1	SiO_2	63.29	20.50
2	Al_2O_3	18.29	4.75
3	Fe_2O_3	4.32	3.70
4	CaO	4.46	63.94
5	MgO	0.72	1.31
6	P_2O_5	0.16	
7	K_2O	2.18	
8	Na_2O	0.75	
9	SO_3	0.1	2.41
10	CL-	0.005	
11	TiO_2	0.61	

II. **Physical Properties**

The fineness of ceramic waste determined by grinding and sieving processes. significantly impacts its reactivity and effectiveness when used as a supplementary cementitious material [47].

III. **Mechanical Properties**

Ceramics are hard and brittle with high compressive strength but low tensile strength. They are resistant to wear and can withstand high temperatures [47].

2.2.2 Applications of Ceramic Waste

2.2.2.1 Construction Materials

I. **Concrete Production**

Ceramic waste has been explored as a partial replacement for cement and aggregate in concrete. Studies have shown that incorporating ceramic waste can improve the mechanical properties and durability of concrete while reducing the environmental impact of cement production.

II. **Mortar**

Ceramic waste can be used in the production of mortar, enhancing its strength and durability. Research indicates that up to 20-30% of cement in mortar can be replaced with ceramic waste without compromising its performance.

2.2.2.2 Ceramic Industry

Recycled ceramic waste can be reintroduced into the ceramic production process. This closed-loop recycling reduces raw material consumption and waste generation.

2.2.2.3 Road Construction

Ceramic waste has been used as a base material for road construction, providing a sustainable alternative to traditional materials. Its high strength and durability make it suitable for this application.

2.3 Previous research works

Several locally available materials were investigated as partial replacement of cement in previous years for cost minimization, availability maximization and to improve concrete performance.

Keshavarz and Mostofinejad (2018) [50] this investigation focused on replacing coarse aggregates with two types of ceramic waste: ordinary red ceramic and porcelain. Porcelain waste increased the compressive strength of concrete by over 41%, while red ceramic waste increased it by 29%. However, the use of porcelain waste also significantly increased water absorption due to its high porosity.

Amitkumar D. Raval, Indrajit N. Patel, Jayesh Kumar Pitroda [51] Use of Ceramic Powder As A Partial Replacement of Cement the OPC cement has been replaced by ceramic waste powder by weight for C-25 grade concrete. The Compressive Strength of C-25 grade concrete increased when the replacement of cement with ceramic waste up to 30% by weight of cement and further replacement of cement with ceramic powder the compressive strength decreased.

Halicka et al. (2013) [52] the examined the use of ceramic brick waste as partial replacement for cement in mortar. They found that replacing up to 15% of cement with ceramic brick waste resulted in similar or improved mechanical properties compared to conventional mortar. Additionally, the study highlighted the potential environmental benefits of reducing cement consumption.

Rashed (2014) [53] this study explored the utilization of Recycled Waste Glass as Fine Aggregate Replacement in Cementitious Materials Based on Portland Cement. The results indicated that a 10% replacement of cement with Recycled Waste Glass waste improved the compressive strength and durability of concrete, making it a viable option for sustainable construction.

Habeeb and Mahmud (2010) [54] conducted on the use of rice husk ash as a partial replacement for cement in concrete. Their findings indicated that RHA could replace up to 20% of cement, resulting in improved workability, reduced water demand, and enhanced strength of concrete. The study highlighted the environmental benefits of using agricultural waste in concrete production.

Poon and Chan (2006) [55] explored the potential of using recycled concrete aggregate as a replacement for natural aggregate in concrete. Their research demonstrated that RCA could replace up to 30% of natural aggregate without significantly affecting the mechanical properties of concrete. The study also emphasized the importance of proper processing and quality control to ensure the performance of RCA concrete.

Oner and Akyuz (2007) [56] conducted a study on the use of GGBS as a partial replacement for cement in concrete. Their findings showed that incorporating GGBS at levels up to 50% significantly improved the compressive strength and durability of concrete. The study also highlighted the environmental benefits of using GGBS in reducing CO2 emissions associated with cement production.

Chapter 3: Methodology

3.1 General

In this chapter, the materials used for the investigation and their sources are described briefly. Moreover, the methods used for testing of ceramic tile waste, constituent materials and concretes are incorporated. All the experimental tests were carried out in Mekelle University and Sur construction PLC's Mekelle city road project laboratories.

3.2 Experimental programs

ceramic waste tiles have been selected to be investigated as partial replacement of cement by considering their availability and environmentally friendly. The ceramic waste tiles were collected from Gezana Real Estate located in the Adi Haki sub-city of Mekelle city. The cement and aggregates were collected and physical tests were conducted for the cement, ceramic waste powder and aggregates to ensure conformity to standards.

The aggregate physical tests carried out in this study are sieve analysis, silt content, unit weight, specific gravity, absorption capacity and moisture content. All the tests were conducted according to ASTM standard test procedures. Normal consistency and both initial and final setting tests were performed for the OPC cement. Moreover, fines test was performed for the ceramic powder.

After making sure that all materials used conform to standard specifications, concrete mix was designed according to ACI method for C-30 concrete grade. As a result, concrete cubes with 0%, 5%, 10%, 15%, 20%, 25% and 30% of ceramic tile waste by weight of cement were casted in addition to controlled mix. At fresh and hardened states slump, compressive and flexural strength tests were investigated using slump cone and compressive strength testing machine respectively.

The compressive strength for hardened concrete of all admixture percentages by extra addition was tested at 3, 7, 14 and 28 days using $150 \times 150 \times 150\ mm3$ concrete cubes and for flexural at 7 and 28 days using $500 \times 150 \times 150\ mm$ concrete samples. In addition to slump and compressive strength tests, setting time test were conducted using Vicat apparatus. Figure 3.1 summarizes the whole research methodology.

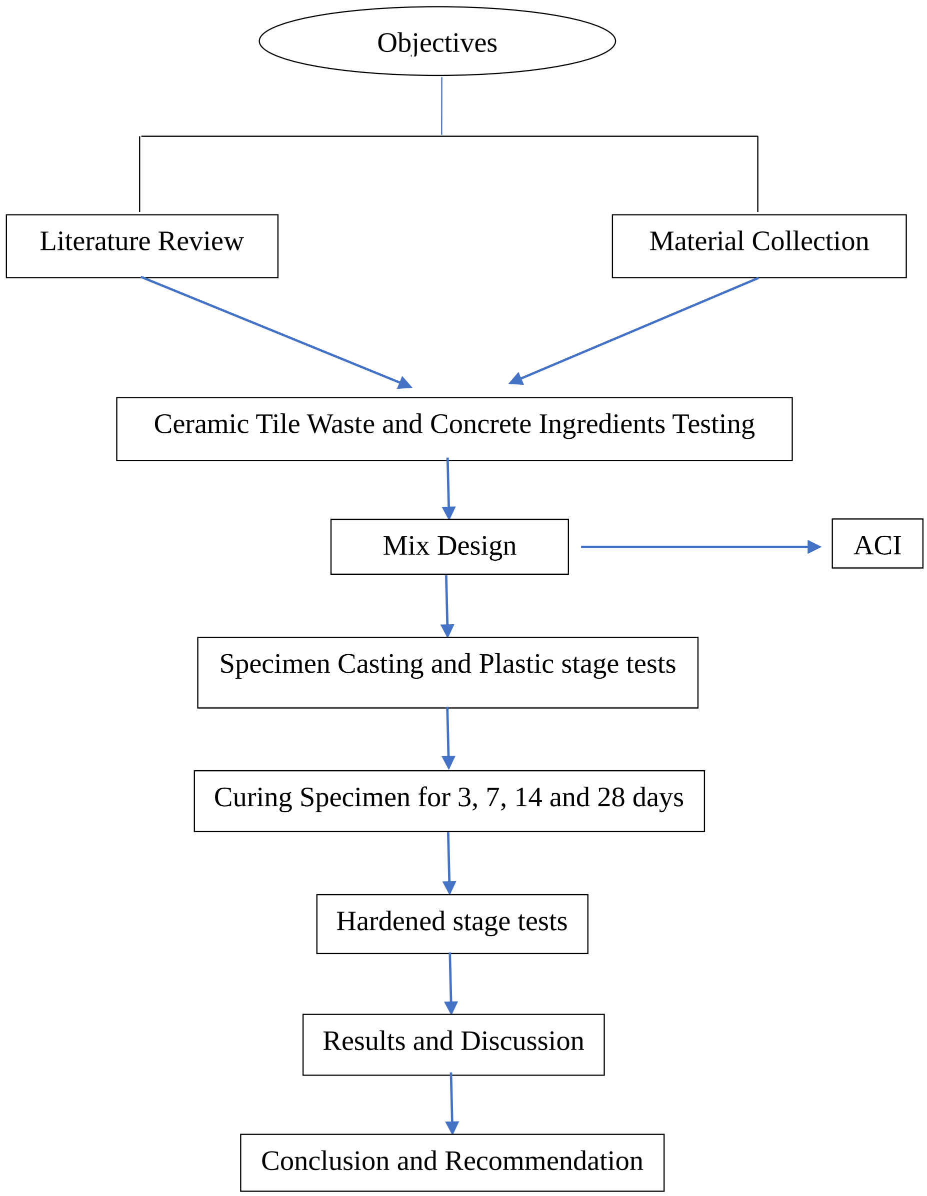

Figure 3-1 Research methodology

3.3 Materials used for the investigation

3.3.1 Cement

Ordinary Portland cement produced by Messebo cement factory has been used throughout the research work. The reason to select only one cement type is due to financial and time limitation to perform experiments. According to the tests result the initial and final setting time was 115 min and 170 min respectively at normal consistency of 27% by weight of Cement.

Table 3.1 normal consistency test result of cement

Wt. of cement (gm)	650	650	650	650	650	650
% of water	24	25	26	27	28	29
Wt. of water (gm)	156	162.5	169	175.5	182	188.5
Penetration depth (mm)	5	6	8	10	-	-

Table 3.2 initial and final setting time test result of cement

Time when water is added = 9:10 A.M			
Time (min)	Penetration (mm)	Time (min)	Penetration (mm)
9:40	40	11:00	28
9:50	40	11:10	23
10:00	39	11:20	15
10:10	38	11:30	13
10:20	37	11:40	10
10:30	37	11:50	7
10:40	33	12:00	5
10:50	30	12:10	0

3.3.2 Aggregates

Aggregates are materials basically used as filler with binding material in the production of concrete. Aggregates form the body of the concrete, reduce the shrinkage and affect economy. Therefore, it is significantly important to obtain right type and quality of aggregates on site.

Natural sand obtained from River sand (51 Kilometers away from Mekelle city) and the coarse aggregates from crusher nearby Quiha (15 Kilometers away from Mekelle city) were used throughout the investigation. All the aggregate tests were conducted in Mekelle University Construction materials laboratory and Sur construction PLC's Mekelle city road project laboratories.

3.3.2.1 Silt content of fine aggregates

Sand is a product of natural or artificial disintegration of rocks and minerals. Sand is obtained from glacial, river, lake, residual and wind- blown (very fine sand) deposited. These deposited, however do not provide pure sand. They often contained dust materials. The presences of such materials in sand to make concrete or mortar decrease the bond between the materials to bind together and hence the strength of the mixture produced resulting in fast deterioration.

According to the Ethiopian Standard it is recommended to wash the sand or reject if the silt content exceeds a value of 6%. From the test result obtained, the silt content of the sand used for this experiment is 3.06%. This is less than the maximum requirement of Ethiopian standard. Therefore, no need to be wash. Appendix 1(A) shows the detail silt content calculations.

Figure 3-2 silt content test

3.3.2.2 Gradation of Aggregates

The sieve analysis of the aggregates was made according to ASTM C 136. The aggregates with gradation that fulfils the Ethiopian standard were used throughout the investigation. The detail sieve analysis calculations are presented in Appendix 1(B).

Figure 3-3 Set of sieves for fine aggregate

3.3.2.3 Specific Gravity, Absorption capacity and Moisture Content

The specific gravity, absorption capacity, and moisture content of fine and coarse aggregate were made according to ASTM C 128 & ASTM C 127 procedures. Table 3.1 summarized the absorption capacity, specific gravity and moisture content of fine and coarse aggregates and the detail calculations are presented in Appendix 1(A) and (B).

Table 3.3 Aggregates test results

S. No.	*Aggregate*	*Absorption Capacity (%)*	*Specific Gravity (SSD)*	*Moisture Content (%)*
1.	Fine	1.94%	2.62	1.95
2.	Coarse	0.25	2.75	0.79

3.3.2.4 Unit weight of coarse Aggregates

As the unit weight of coarse aggregate is an input for mix design, the unit weight test was carried out using three litters cylinder as shown in Figure 3.5. From the test result, the unit weight of the coarse aggregate used for the investigation was obtained 1591.55 $^{Kg}/_{m3}$. Appendix 1(B) shows the detail unit weight calculation.

Figure 3-4 Unit of coarse aggregates

3.3.3 Water

Throughout the investigation potable water was consistently used for all stages of the concrete preparation process. This included the washing of fine aggregates to remove any impurities that might affect the quality of the mix, ensuring a clean and consistent aggregate. Potable water was also employed during the mixing and curing process to maintain uniformity and ensure proper hydration of the cement.

3.3.4 Ceramic tile waste powder

The ceramic tile wastes used for this test is comes from construction and demolition(C&D) buildings were collected from Gezana Real Estate located in the Adi Haki sub-city of Mekelle city. The tiles were originally imported from the United Arab Emirates (U.A.E.) and manufactured by RAK Ceramics. Those ceramic tiles are applicable to this test by crushing the wastes into powder as shown on the figure below. the fineness of ceramic tile powder is found to be 7.5% as shown on the table 3.3 below.

Table 3.4 Unit of coarse aggregates

Observation	1	2	3
W = Mass of cement sample (g)	50	50	50
R = Mass of residue (g)	3.5	4	3.75
Fineness of cement F (%) = 100- $\frac{R*100}{W}$	93	92	92.5
Average fineness of cement (%)	92.5		

Figure 3-5 fineness test for cement

3.4 Production of concrete mixes

3.4.1 Mix proportioning

After finishing concrete ingredient tests, concrete with 30MPa grade at age of 28 day was designed. The mix design was carried out according to ACI design procedures. The mix design and summary of mix proportions are presented in Appendix (2) and (3).

Table 3.5 fineness test for cement

Material	*Quantity* $\frac{\mathrm{Kg}}{\mathrm{m3}}$
Cement	405
Water	173
Fine aggregate	713
Coarse aggregate	1138
W/C	0.47

3.4.2 Batching of concrete materials

According to the mix proportions quantities of cement, fine aggregate, coarse aggregate was batched by weight measurement. However, the amount of water was measured by volume measurement. this is primarily because water is easier to measure in liquid form using volumetric methods like liters or gallons, which are convenient and practical for field applications.

3.4.3 Mixing of concrete materials

The concrete mixing was performed according to the standard method of making and curing test specimens in the laboratory ASTM C 192. Initially, the aggregates and cements were mixed dry for one minute before addition of water and for another two minutes the concrete were mixed with the mixing water for the controlled sample. Similarly, the concretes having ceramic tile waste with dosage of 0%, 5%, 10%, 15%, 20%, 25% and 30% were casted for comparison.

3.4.4 Curing of concrete cubes

After 24 hours of casting, the concrete cube molds were carefully removed to prevent any defects or damage to the samples. This careful handling is crucial because the concrete is still in an early stage of setting and gaining strength making it vulnerable to cracking or other imperfections. Once the molds are removed, the cubes are placed in a water tank for curing where they remain submerged until the testing period. Curing in water is essential as it ensures a consistent supply of moisture, which is critical for the hydration process of the cement. This process is vital to achieving reliable and accurate test results for the concrete's compressive strength and other properties.

3.5 Specimen testing

The major tests conducted for the investigation are slump test, compressive strength tests and flexural strength test. The workability and compressive strength tests and flexural strength test were performed according to ASTM standard test procedures. slump cone, compressive strength testing machine and universal testing machine were used for workability, compressive strength and flexural strength tests respectively.

3.5.1 Slump test

The slump test was carried out in accordance with ASTM C143 standards to assess the workability of the concrete mix. The test involved using a standardized metal slump cone with a height of 300 mm, a bottom diameter of 200 mm, and a top diameter of 100 mm. Freshly mixed concrete with dosage of 0%, 5%, 10%, 15%, 20%, 25% and 30% of ceramic tile waste by weight of cement were filled into the cone in three layers. After filling, the cone was carefully lifted vertically, allowing the concrete to slump under its weight. The decrease in height of the concrete, measured from the original height of the cone to the highest point of the slumped concrete, was recorded as the slump value in millimeters. This test was repeated for consistency, and the average value was used to represent the workability of the concrete mix.

Figure 3-6 Slump test

3.5.2 Compressive strength test

The compressive strength test was carried out following the ASTM C39 standard, which is widely recognized for determining the compressive strength of concrete specimens. Concrete samples were cast in cube molds with dimensions of 150 mm. After completing the designated curing period, the specimens were tested using a calibrated compression testing machine to ensure precise measurements. The concrete cubes, including those with added ceramic tile waste, were subjected to compression testing at the ages of 7, 14, and 28 days. During the test, the cube samples were compressed until failure, and the maximum load at which the specimen failed was recorded. The compressive strength was then calculated by dividing this maximum load by the cross-sectional area of the cube. To ensure accuracy and consistency, multiple samples were tested for each age group, and the average compressive strength was taken as the representative value. This rigorous testing process ensures the reliability of the results, providing valuable insights into the concrete's performance.

Figure 3-7 compressive strength test

3.5.3 Flexural strength test

The flexural strength test was conducted according to the ASTM C293 standard. Concrete beams were cast with dimensions of 150 mm in width, 150 mm in depth, and 500 mm in length. These beams were cured. After curing, the specimens were subjected to a single-point loading test using a calibrated universal testing machine. The beam samples were crashed at the age of 7 and 28 for samples made by addition of ceramic tile waste. The load was applied at a constant rate until the beam failed, and the maximum load at failure was recorded. Multiple specimens were tested to ensure accuracy, and the average value was taken as the representative flexural strength.

Figure 3-8 Compressive and flexural strength tests

Chapter 4: Results and Discussion

4.1 General

This chapter presents the results of tests conducted to evaluate the impact of partially replacing cement with ceramic waste tiles in C30 concrete. The focus is on three key properties: slump value, compressive strength and flexural strength. By varying the replacement levels from 5% to 30%, the study examines how ceramic waste influences the workability, strength, and overall performance of the concrete. The findings will provide insights into the feasibility of using ceramic waste as a sustainable alternative in concrete production.

4.2 Slump test results

The slump test is a measure of the workability or consistency of fresh concrete. It indicates how easily the concrete can be mixed, placed, and compacted without segregation. By varying the percentage of cement replaced with ceramic waste tiles from 5% to 30%, the impact on the workability of the concrete mix was examined and compared with reference concrete as shown in Table 4.1. The slump values recorded for each mix will provide insight into the potential changes in fluidity and cohesion as the replacement level increases.

Table 4.1 workability test results

Mix code	ceramic tile waste powder (%)	W/C ratio	Slump (mm)
MC1	0	0.47	46
MC5	5	0.47	41
MC10	10	0.47	38
MC15	15	0.47	33
MC20	20	0.47	29
MC25	25	0.47	25
MC30	30	0.47	21

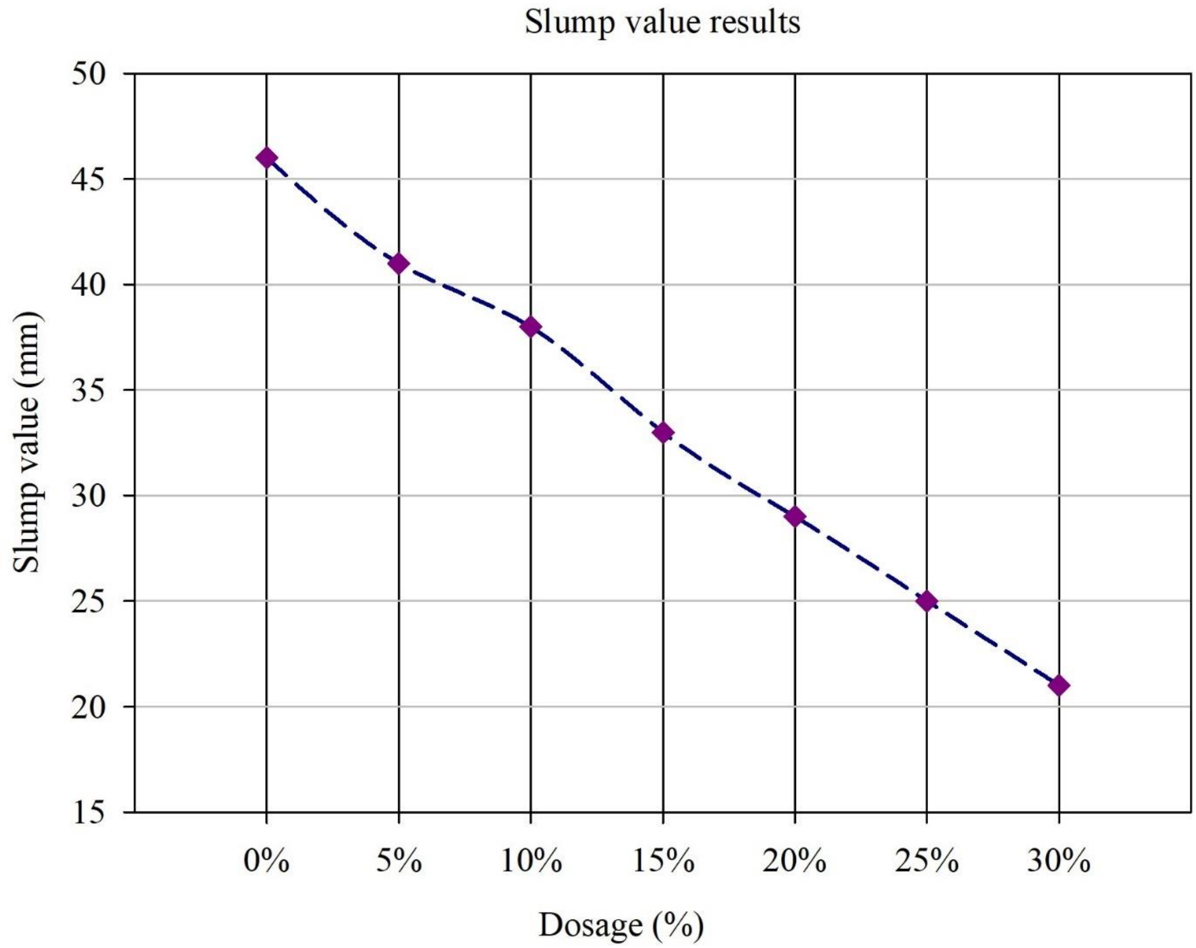

Figure 4-1 Effect of ceramic tile waste on workability of concrete

As seen in Table 4.1 and Figure 4.1 the slump test results clearly demonstrate a decrease in concrete workability as the percentage of ceramic tile waste powder increases, which initially targeted a slump value range of 25-50 mm. The tests were conducted with a constant water-cement (W/C) ratio of 0.47 across all mixes. The control mix, containing 0% ceramic tile waste, achieved a slump of 46 mm, indicating good workability. However, with the introduction of ceramic tile waste the slump values progressively decreased 41 mm at 5% replacement, 38 mm at 10%, 33 mm at 15%, 29 mm at 20%, 25 mm at 25%, and reaching the lowest value of 21 mm at 30% replacement.

This trend suggests that as the ceramic tile waste content increases, the mix becomes stiffer and less workable. The data indicates that while ceramic tile waste can be used as a partial replacement for cement careful consideration must be given to its impact on workability. For practical applications, especially where high workability is required, it may be necessary to adjust the water content or incorporate chemical admixtures, such as superplasticizers to counteract the reduced slump and ensure the concrete can be effectively placed and compacted.

4.3 Compressive strength results

Compressive strength is a key parameter that defines the ability of concrete to withstand loads that tend to compress it. It is a critical property for structural applications. In this study the compressive strength of concrete mixes with varying percentages of ceramic waste tile replacement was assessed at different curing periods as shown in Table 4.2. The results will reveal the effect of the ceramic waste on the strength development of the concrete, highlighting any potential benefits or drawbacks in using such a replacement.

Table 4.2 Effect of ceramic tile waste on workability of concrete

S.No.	Mix code	Dosage (%)	7 days (Mpa)	14 days (Mpa)	28 days (Mpa)
1	MC1	-	23.10	30.15	33.17
2	MC5	5	24.22	31.31	35.25
3	MC10	10	28.18	36.60	40.26
4	MC15	15	26.33	33.41	37.21
5	MC20	20	25.16	32.67	34.94
6	MC25	25	22.74	27.53	31.64
7	MC30	30	20.15	26.17	28.79

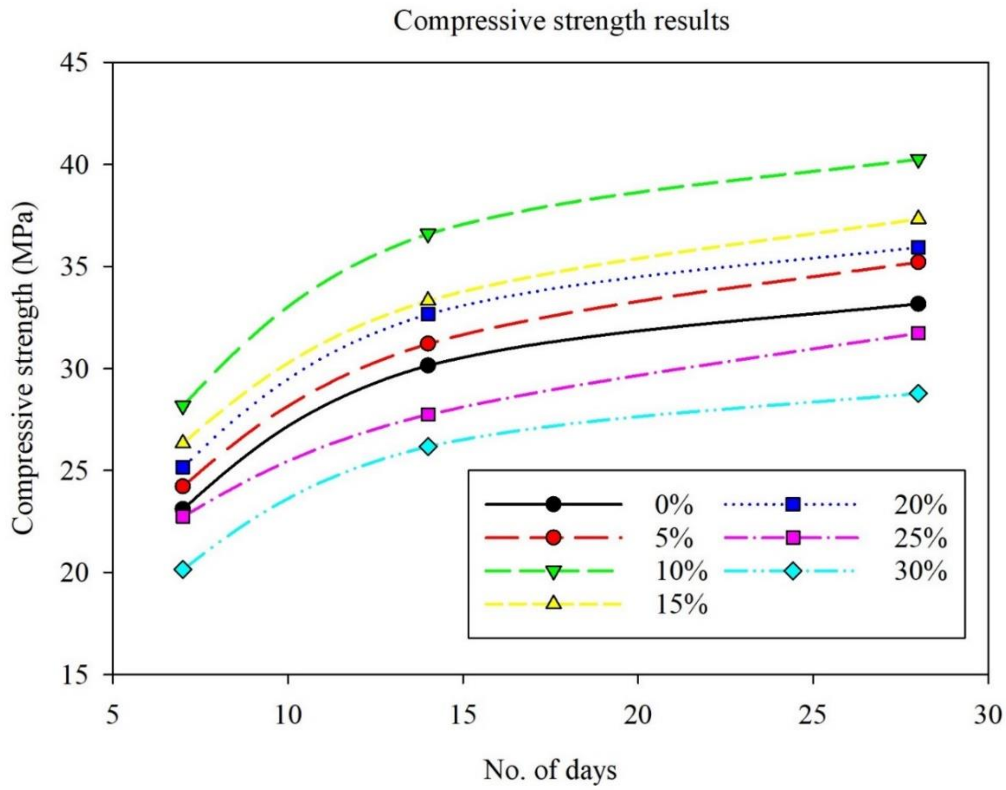

Figure 4-2 Effect of ceramic tile waste on compressive strength

As shown from the table 4.2 and graph 4-2 the compressive strength of concrete with varying dosages of ceramic tile waste as partial replacement for cement demonstrates significant variations across different curing periods. The compressive strength was measured at 7, 14, and 28 days to evaluate the effect of the replacement levels on the properties of the concrete.

The compressive strength of concrete incorporating ceramic tile waste as a partial replacement for cement shows distinct trends at 7, 14, and 28 days of curing. At all three curing stages, the compressive strength initially increases with a 5% to 10% replacement, peaking at 10%, where the strength consistently surpasses that of the control mix. Specifically, the 10% replacement mix achieves the highest strengths of 28.18 MPa, 36.60 MPa, and 40.26 MPa at 7, 14, and 28 days respectively compared to the control mix which recorded 23.10 MPa, 30.15 MPa, and 33.17 MPa at the same intervals. However, when the replacement level exceeds 15%, the compressive strength begins to decline, falling below the control mix at higher dosages, such as 25% and 30%. This indicates that while a moderate addition of ceramic tile waste can enhance the strength of concrete and excessive replacement weakens the cement matrix resulting in reduced compressive strength over time.

4.4 Flexural strength results

Flexural strength is a critical measure of a concrete's ability to resist bending or flexural stress, which is particularly important for structural elements like beams and slabs that are subjected to such forces in service. This property reflects the tensile strength of the concrete, as it assesses how well the material can handle forces that cause it to bend without cracking. In the investigation, the flexural strength of concrete was analyzed with varying levels of cement replacement using ceramic tile waste. This analysis provided valuable insights into how the inclusion of ceramic waste tile affects the tensile properties of the concrete. By examining these different levels of replacement, the study aimed to determine the optimal amount of ceramic tile waste that could be used without compromising the concrete's structural integrity, as shown in Table 4.3. The results from this analysis are crucial for understanding the balance between sustainability and performance in concrete mixes incorporating waste materials.

Table 4.3 flexural strength test results

S.No	Mix code	Dosage (%)	7 days (Mpa)	28 days (Mpa)
1	MC1	-	2.67	3.95
2	MC5	5	2.76	4.25
3	MC10	10	2.85	4.31
4	MC15	15	2.47	3.81
5	MC20	20	2.43	3.72
6	MC25	25	2.35	3.59
7	MC30	30	2.17	3.42

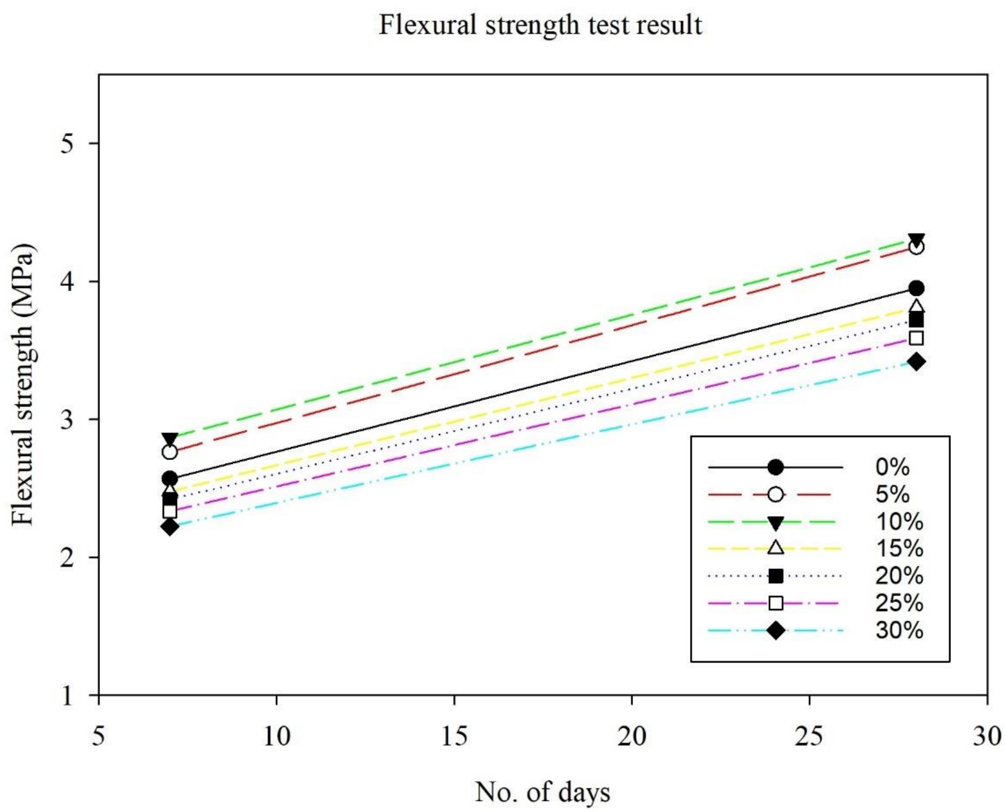

Figure 4-3 Effect of ceramic tile waste on flexural strength

As shown from the table 4.3 and graph 4-4 the flexural strength of concrete incorporating ceramic tile waste as a partial replacement for cement displays significant variations at 7 and 28 days of curing.

The flexural strength results reveal that at both curing stages the strength of the concrete initially increases with the introduction of ceramic tile waste peaking at a 10% replacement level. Specifically, the mix containing 10% ceramic tile waste achieves the highest flexural strengths of 2.85 MPa at 7 days and 4.31 MPa at 28 days surpassing the control mix. However, as the replacement level increases beyond 10% the flexural strength begins to decline, with higher dosages such as 30% resulting in strengths of 2.17 MPa at 7 days and 3.42 MPa at 28 days both of which are lower than the control mix. This trend suggests that while a moderate addition of ceramic tile waste enhances the flexural strength of concrete but excessive replacement leads to a weakening of the cement ultimately reducing the flexural strength over time and compromising the structural integrity of the concrete. This balance between waste incorporation and maintaining strength is crucial for sustainable construction practices.

4.5 Cost comparison results

4.5.1 General

The focus on sustainable development is vital due to the considerable environmental impact of human activities especially within the construction industry. Cement is an essential ingredient in concrete, has seen increased demand driven by the construction sector leading to supply shortages and high costs. At the same time, ceramic tile waste from construction and demolition is usually discarded in landfills, increasing waste management problems. By substituting a portion of cement with this waste, we can tackle waste disposal challenges while providing a solution to material shortages and high costs, thereby advancing more sustainable construction practices.

4.5.2 Considerations

A. **Ingredients unit price rate:** A concrete ingredients material cost survey made, specifically in Gezana real estate project in Mekelle, have shown, the material cost for 16m3 of river sand were 24,000 ETB. While the 16m3 coarse aggregates material cost was 32,000 ETB in average. This cost is including both productions, loading and transportation costs. As of the survey conducted, 2500 ETB is to be paid for 18, 000 liters pure water in Mekelle. Calculating this in to a price per cubic meter would be needed and it is shown in the table below. Messebo cement factory has set the material cost of cement including the transportation in all location s of the region, Tigray. Cost of cement is 985 ETB per quintal (100Kg.) in Mekelle. This material costs were the latest as of August 2024.

Table 4.4 Material cost of concrete ingredients in Mekelle

Concrete Ingredients	material cost in Mekelle
OPC Cement	9.85 ETB/Kg
sand	1500 ETB/m^3
Coarse aggregate	2000 ETB/ m^3
Water	0.14 ETB/Lit

B. **Ceramic tile waste unit price rate:** The unit price rate for ceramic tile waste sourced from construction and demolition sites is determined by considering several cost components associated with the collection, transportation and processing.

The collection costs encompass the expenses related to gathering ceramic tile waste from construction and demolition sites. This includes labor costs, estimated at 0.64 ETB per Kg, for the manual collection of the waste. Additionally, transportation costs are incurred to move the collected waste from the site to the processing facility, which is estimated at 1.5 ETB per Kg. Together, these costs total 2.14 ETB per Kg for the collection phase.

Processing costs involve converting the collected ceramic tile waste into a fine powder suitable for use in concrete. This includes crushing and grinding costs, estimated at 3 ETB per Kg, which cover the mechanical reduction of the waste material to the desired particle size. In total the costs amount to 5.14 ETB per Kg.

C. **Ingredients required to produce 1m3 concrete :** We know the ingredients required to produce one cubic meter of concrete volume from the mix design prepared as shown in the table below.

Table 4.5 Ingredients required to produce 1 m3 concrete

Mix code	Cement $\frac{Kg}{m3}$	% of Ceramic	Ceramic tile powder Kg	Water $\frac{Lit}{m3}$	FA $\frac{Kg}{m3}$	CA $\frac{Kg}{m3}$
MC0	405	-	-	173	713	1138
MC5	384.75	5	20.25	173	713	1138
MC10	364.5	10	40.5	173	713	1138
MC15	344.25	15	60.75	173	713	1138
MC20	324	20	81	173	713	1138
MC25	303.75	25	101.25	173	713	1138
MC30	283.5	30	121.5	173	713	1138

4.5.3 Cost Analysis

A. Direct cost

Estimating the cost of any work items include estimating the cost of material cost, labor cost and equipment cost [28]. Since the labors and equipment to be assigned for concrete production made with ceramic tile waste and the cement remains the same, both labor and equipment cost of a concrete produced using both materials remains the same as well. While the material cost varies, since the production and transportation cost of different materials to be supplied from different location do differ. Material cost includes both production and transportation costs.

Table 4.6 Concrete direct cost with different ceramic replacement proportion

% Replacement	Cement cost	Water cost	coarse aggregate cost	sand cost	Ceramic tile waste cost	Total material cost (ETB)
0	3989.25	24.22	833.70	503.45	-	5255.38
5	3789.79	24.22	833.70	503.45	104.085	5200.50
10	3590.33	24.22	833.70	503.45	208.17	5064.62
15	3390.86	24.22	833.70	503.45	312.255	4969.24
20	3191.4	24.22	833.70	503.45	416.34	4873.87
25	2991.94	24.22	833.70	503.45	520.425	4778.49

In Table 4.6, the total material cost decreases as the percentage of ceramic tile waste replacement increases. At 0% replacement, the cost is ETB 5255.38, while at 25% it drops to ETB 4778.49, showing a savings of ETB 476.89. At 10% replacement, the concrete not only achieves a notable cost reduction but also maintains strong structural performance, making it the optimal recommendation for balancing cost efficiency and material strength.

B. Indirect cost :

Indirect costs are costs with no direct relation to the cost of ingredients. In the cost analysis of concrete oil shale, no indirect cost is needed. Because, the indirect costs of concrete produced with oil shale or river sand as a fine aggregate remains the same. It will not be valuable in the comparison.

Chapter 5: Conclusions and Recommendations

This study aimed to investigate the potential of ceramic tile waste as a partial replacement for cement in concrete with a focus on its effects on the workability, compressive and flexural strength of the resulting concrete mix. Through a series of experimental analyses and comparisons with a control mix the research explored the viability of utilizing this waste material as a sustainable alternative in the construction industry. The findings provide valuable insights into the optimal replacement levels that can enhance concrete performance while addressing environmental concerns related to waste management. Based on these results, the following conclusions and recommendations are proposed to guide further research and practical applications in the field.

5.1 Conclusions

1. The investigation results revealed increasing ceramic tile waste in concrete decreases workability. Therefore, to mitigate the loss of workability it is recommended to adjust the water-to-cement ratio or incorporate admixtures when using ceramic tile waste in concrete mixtures.
2. 10% replacement of cement with ceramic tile wastes resulted highest compressive and flexural strengths with 40.26 MPa and 4.31 MPa test results at 28 days.
3. The most effective dosage for achieving the needed compressive strength is a 25% replacement of cement with ceramic tile waste resulted with 31.64 MPa.
4. The optimal replacement level for achieving the flexural strength is 10%. At this dosage concrete exhibits superior bending resistance. Exceeding this optimal percentage however, results in reduced flexural performance.
5. The cost analysis revealed that incorporating ceramic waste significantly reduces material costs. which provided a balanced approach lowering cement expenses while maintaining concrete strength and performance.

6. The study demonstrates that a 10% replacement of ceramic tile waste in concrete achieves a compressive strength of 40.26 MPa and maximizes flexural strength. This level provides excellent bending resistance which is crucial for structural performance. Although 25% replacement meets the required compressive strength but it significantly reduces flexural performance. Therefore, a 10% replacement is recommended for practical use effectively balancing both strength properties. This level strikes a balance between utilizing waste materials and maintaining high structural performance and making it an effective and sustainable choice for enhancing concrete strength.

5.2 Recommendations

Based on the study, the following recommendations and future works are forwarded.

Recommendations

1. It is recommended to use ceramic tile waste powder as replacement for cement in concrete production. The recommended dosage provides the best balance between sustainability and mechanical performance and making it suitable for a wide range of construction applications.
2. Adjustments in water content or the use of admixtures should be considered when incorporating ceramic tile waste to counteract the reduced workability and ensure the mix can be effectively placed and compacted.
3. Information about using ceramic tile waste as an alternative for enhancing concrete quality should be communicated to stakeholders in the construction industry.

Future works

1. Investigation on the effects ceramic tile waste on long term compressive strength and durability of concrete
2. Investigation on the effects of ceramic tile waste on the mechanical properties of concrete for different cement types
3. Investigation on the effects of ceramic tile waste on the mechanical properties of different concrete strengths

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Appendices

Appendix 1: Concrete materials' tests

A) Fine aggregates

I. Silt content determination

Amount of Sand Sample=100gm and Amount of Water=200ml

Observations	1	2	3
Total sand and silt (cm), A	5.5	5.3	5.2
Amount of clean sand (cm), C	5.35	5.1	5.05
Amount of silt deposited above the sand (cm), $B = (A - C)$	0.15	0.2	0.15
$Silt\ content\ (\%) = \frac{B}{C} \times 100\%$	2.28	3.92	3.00
Average silt content, %	3.06		
Remark: Silt contents are below the ES limit 6% and thus acceptable			

II. Gradation (Sieve analysis)

S. No.	*Sieve size (mm)*	*Retained wt. (g)*	*Percentage retained (%)*	*Cumulative retained (%)*	*Cumulative passing (%)*	*Upper and lower limits (%)*
1.	9.5	0.0	0.0	0	100	100
2.	4.75	79.0	4.8	4.8	95.2	95-100
3.	2.36	45.8	2.8	7.6	92.4	80-100
4.	1.18	126.2	7.7	15.3	84.7	50-85

5.	0.6	457.2	28.1	43.4	56.6	25-60
6.	0.3	563.8	34.6	78	22	10-30
7.	0.15	270.0	16.6	94.6	5.4	2-10
8.	Pan	87	5.4	100	0	-
			FM	$\frac{245}{100} = 2.45$		

III. Specific Gravity and water absorption determination

Observations	*1*	*2*	*3*
Specimen Oven dry Weight (g), A	490	491	490
Water Filled Pycnometer Weight (g), B	1538.00	1538.00	1538.00
Specimen + Water + Pycnometer Weight (g), C	1848.0	1847.0	1851.5
Specimen SSD Weight (g), S	500	500	500
$G_{SSD} = \frac{S}{(B+S-C)}$	2.63	2.57	2.67
Average G_{SSD}	2.62		
Absorption Capacity (%) $=\frac{S-A}{A}$ *100%	2.04	1.83	2.04
Average absorption capacity (%)	1.95 %		

IV. Moisture content determination

$$M_c = \frac{\text{Wet wt} - \text{Dry wt}}{\text{Dry wt}} *100\%$$

Observation	1	2	3
Mass of empty, clean can, (g)	330	355	320
Mass of can + moist sand, (g)	2202.7	1562.79	1525.57
Mass of can + dry sand, (g)	2153.5	1536.8	1499.5
M_C (%)	2.7	2.2	2.21
Average M_C (%)	2.37%		

B) Coarse aggregates

I. Unit weight determination

Observation	*1*	*2*	*3*
Cylinder wt (Kg)	2.97	2.97	2.97
Cylinder + Compacted wt (Kg)	7.71	7.73	7.79
Compacted wt(kg), A	4.74	4.76	4.82
Cylinder volume (m^3), B	$3*10^{-3}$		
$Unit\ wt = \frac{A}{B}\ \frac{Kg}{m3}$	1580	1587.33	1607.33
Average unit weight = $\frac{Kg}{m3}$	1591.5		

II. Gradation

S. No.	Sieve size (mm)	Retained wt (g)	Percentage retained %	Cumulative retained %	Cumulative Passing %	Upper and lower (%)
1.	37.5	0	0	0	100	95-100
2.	28	0	0	0	100	-
3.	19	508	8.9	8.9	91.1	30-70
4.	14	981.37	17.1	26	74	-
5.	9.5	3420.4	59.6	85.6	14.4	10-35
6.	4.75	631.29	11	96.6	3.4	0-5
7.	0.075	177.91	3.1	99.7	0.3	
8.	Pan	28.7	0.3	100	0	-

III. Specific Gravity and Water Absorption determination

Observation	*1*	*2*	*3*
Weight of oven dry test sample in air, g A	2241.5	2286.0	2265
Weight of saturated surface dry test sample in air, g B	2246	2293	2271
Weight of saturated surface dry test sample in water, g C	1432.2	1452.6	1428.5
$G_{SSD} = \frac{\boldsymbol{B}}{(\boldsymbol{B}-\boldsymbol{C})}$	2.76	2.73	2.69
Average G_{SSD}	2.73		
$Absorptiok\ Capacity$ (%) = $\frac{\boldsymbol{B}-\boldsymbol{A}}{(\boldsymbol{A})} \times 100\%$	0.2	0.31	0.26
Average absorption capacity %	0.26		

IV. Moisture content determination

Observation	*1*	*2*	*3*
Mass of empty, clean can (g)	50.4	50.9	50.5
Mass of can + moist aggregate (g)	644.30	534.10	625.5
Mass of can + dry sand (g)	639.80	530.20	621.2
M_C (%)	0.76	0.81	0.75
Average M_C (%)	0.77		

Appendix 2: Mix design calculations

The mix design was conducted for C- 30 Concrete grade cubes using ACI method design procedures as shown in the following steps.

Laboratory results		
Coarse aggregates	Maximum aggregate size	25mm
	Unit weight	1591.5 $\frac{Kg}{m3}$
	Specific gravity G_{SSD}	2.73
	Absorption capacity	0.26%
	Water content	0.77%
Fine aggregates	Fineness modulus	2.45
	Specific gravity G_{SSD}	2.62
	Water absorption	1.95%
	Moisture content	2.37 %
Specific gravity of Messebo OPC (G) = 3.15		

The required mix design strength characteristic strength of 30MPa for cube.

assuming 5% of results are permitted to fall below the specified design strength,

The mean strength, fm = fmin + ks

= 30 + 1.64*3.5

= 35.74 Mpa

1) *Slump requirement*

Since the mix design is for mass concrete, the recommended slump requirement is the range between 25-75mm, take 25-50mm

2) *Maximum size of aggregate*

From sieve analysis the maximum size of aggregate was found 25mm as seen in table above.

3) *The approximate mixing water and air content*

Water content=179 kg/m^3 and air content =1.5% were found from ACI committee report for mix design table 6.3.3. Approximate mixing water and air content for different slumps and maximum size of aggregates

4) *Determination of W/C*

W/C=0.47 were found from ACI committee report for mix design table 6.3.4.a. relationship between water cement and compressive strength of concrete by interpolation for target value 35.74MPa

5) *Cement content determination*

The Cement content was determined by dividing the water content to w/c found on above steps.

$$W/C = \frac{\text{Wt.water}}{\text{Wt.cement}}$$

$$\text{Wt. cement} = \frac{\text{Wt.water}}{W/C}$$

$$= 179\frac{\text{Kg}}{\text{m3}} \ / \ 0.47$$

$$= 405 \text{ Kg}$$

$$\text{Volume of cement} = \frac{405 \text{ Kg}}{3.15*100 \text{ Kg/m3}}$$

$$= 0.129 \text{ m}^3$$

6) *Coarse Aggregate content determination*

The coarse aggregate content is found by multiplying of the unit weight found from laboratory and volume of coarse aggregate per unit volume of concrete (ACI committee report for mix design table 6.3.6.)

volume of coarse aggregate content according to ACI 211.1-91, A1.5.3.6 table is 0.71 m3

Weight (Dry) = 0.71 * 1591.55

= 1130 kg

7) *Fine aggregate content using volume method*

Air	0.015 M^3
Cement	0.129 M^3
CA	0.41 M^3
Water	0.179 M^3
Volume of Air + Cement + CA + Water	0.733 M^3
Volume of FA = 1 – 0.733	0.267 M^3
Fine aggregate content = 0.267*2.62*1000	700 Kg M^3

8) *batching weight adjustment and water adjustment*

Wet coarse aggregate = (1+MC) * Wt. CA

= 1.0077 * 1130 =1138 KG

Wet fine aggregate = (1+MC) * Wt. FA

= 1.0195 * 700 = 713 Kg

Water adjustment for CA = Wt. agg * (MC – Absorption)

= 1130 * (0.0079-0.0026) = 6.1 Kg

Water adjustment for FA = Wt. agg * (MC – Absorption)

= 713 * (0.0237-0.0195) = 0.07 Kg

Adjusted water required = 179 – 6.1 – 0.07

= 173 Kg

Therefore, the adjusted batch masses are summarized below:

Material	*Quantity* $\frac{\text{Kg}}{\text{m3}}$
Cement	405
Water	173
Fine aggregate	713
Coarse aggregate	1138
W/C	0.47

Appendix 3: Summary of mix proportions

Mix code	Cement Type	Cement $\frac{Kg}{m3}$	% of Ceramic	Ceramic tile powder Kg	Water $\frac{Lit}{m3}$	FA $\frac{Kg}{m3}$	CA $\frac{Kg}{m3}$
Controlled (reference) Mix							
MC0	Messobo OPC	405	-	-	173	713	1138
MC5	Messobo OPC	384.75	5	20.25	173	713	1138
MC10	Messobo OPC	364.5	10	40.5	173	713	1138
MC15	Messobo OPC	344.25	15	60.75	173	713	1138
MC20	Messobo OPC	324	20	81	173	713	1138
MC25	Messobo OPC	303.75	25	101.25	173	713	1138
MC30	Messobo OPC	283.5	30	121.5	173	713	1138

Appendix 4: Compressive and flexural strength calculations

A. Compressive strength of concrete:

$\sigma = \frac{P}{A}$ Where, σ = Compressive strength (MPa)

P = Average maximum load (KN)

A = Cross sectional area (mm^2)

7 days' compressive strength results

Dosage (%)	Average Mass (Kg)	Area (mm2)	Average Load (KN)	σ (MPa)
0	8.35	22500	519.75	23.10
5	8.31	22500	544.95	24.22
10	8.26	22500	634.10	28.18
15	8.22	22500	592.42	26.33
20	8.13	22500	566.02	25.16
25	8.08	22500	511.65	22.74
30	8.01	22500	453.42	20.15

14 days' compressive strength results

Dosage (%)	Average Mass (Kg)	Area (mm2)	Average Load (KN)	σ (MPa)
0	8.65	22500	678.32	30.15
5	8.59	22500	678.38	31.31
10	8.53	22500	823.50	36.60
15	8.48	22500	751.72	33.41
20	8.42	22500	735.08	32.67
25	8.37	22500	619.42	27.53
30	8.35	22500	588.87	26.17

28 days' compressive strength results

Dosage (%)	Average Mass (Kg)	Area (mm2)	Average Load (KN)	σ (MPa)
0	8.87	22500	746.5	33.17
5	8.81	22500	793.12	35.25
10	8.76	22500	905.85	40.26
15	8.72	22500	837.22	37.21
20	8.65	22500	808.60	34.94
25	8.61	22500	711.9	31.64
30	8.55	22500	647.74	28.79

B. Flexural strength of concrete:

$R = \frac{3Pa}{\mathrm{bd2}}$ Where, R = modulus of rupture (MPa)

P = maximum applied load (KN)

a = average distance between line of fracture and the nearest support (mm)

b = average width of specimen (mm)

d = average depth of specimen (mm)

7 days' flexural strength results

Dosage (%)	L (mm)	B (mm)	D (mm)	Average Load (KN)	Flexural strength (MPa)
0	500	150	150	13.06	2.67
5	500	150	150	13.50	2.76
10	500	150	150	13.94	2.85
15	500	150	150	12.08	2.47
20	500	150	150	11.89	2.43
25	500	150	150	11.49	2.35
30	500	150	150	10.61	2.17

28 days' flexural strength results

Dosage (%)	L (mm)	B (mm)	D (mm)	Average Load (KN)	Flexural strength (MPa)
0	500	150	150	19.32	3.95
5	500	150	150	20.79	4.25
10	500	150	150	21.08	4.31
15	500	150	150	18.64	3.81
20	500	150	150	18.20	3.72
25	500	150	150	17.56	3.59
30	500	150	150	16.73	3.42