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ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL
ENGINEERING**



**UTILIZATION OF CRUSHED CERAMIC WASTE
TILES AS A PARTIAL REPLACEMENT OF COARSE
AGGREGATE IN CEMENT CONCRETE MAKING**

By

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Addis Ababa

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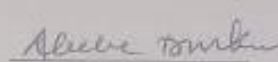
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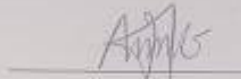
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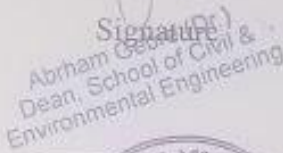
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ABSTRACT

The main goal of sustainable construction can be greatly advanced by using waste materials in the production of concrete. Ceramic materials are being used more frequently in new projects as electrical insulators, sanitary fitting, and tiles, among other things. However, ceramic materials produce a significant amount of waste during production, transportation, and installation due to their fragility. As a result, this research outlines an experimental investigation of utilization of crushed ceramic waste tiles in cement concrete making by substituting the coarse aggregate. Before undergoing the ceramic wastes through the fundamental physical tests, they were manually crushed with a Ball-peen hammer and sieved.

As part of the research, concrete-making materials (coarse aggregate, fine aggregate and crushed ceramic tiles) were tested in the material laboratories. Concrete mix designs for the C-20 and C-25 grades of concrete were produced using the ACI 211.1 mix design procedure. Each concrete grade's natural coarse aggregate was replaced with crushed waste ceramic tiles at weights of 10%, 20%, and 30%. To compare test results with those obtained by partial substitution. A control mix of 0% crushed and sieved ceramic tiles was made. For the C-20 and C-25 classes of concrete, a total of eight concrete mixes including the control samples were produced.

Each grade of fresh concrete was subjected to a slump test and fresh concrete density. Compressive strength, conducted on the seventh, fourteenth and twenty-eighth day, whereas the flexural strength, and splitting tensile strength tests were done on the twenty-eighth day.

The results of the partial replacement of ceramic waste tiles tests were obtained to be marginally higher than those obtained by the control mix. After examining the results, it was established that the percentage of residual ceramic tiles to incorporate into the concrete mix that results the highest strength is 20% for C20 and C25 concrete classes. The overall findings of the results showed that incorporating waste ceramic tiles partially as coarse aggregate improved the compressive strength, split tensile strength and flexural strength.

Key words: sustainable, ceramic wastes, slump, compressive strength, split tensile strength, and flexural strength.

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LIST OF ABBREVIATIONS

%	Percentage
AAiT	Addis Ababa Institute of Technology
A ₂ O ₃	Aluminum Oxide
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
B C	Before Christ
CA	Ceramic Aggregate
C20	Concrete Grade with characteristic strength of 20 MPa by 28 th day
C25	Concrete Grade with characteristic strength of 25 MPa by 28 th day
Cm ³	Centimeter cube
D	Diameter
EBCS	Ethiopian Building Code Standard
E.C	Ethiopian calendar
ES	Ethiopian Standard
ETB	Ethiopian Birr
Fe ₂ O ₃	Ferric Oxide
FM	Fineness Modulus
Gm	gram
H	Height
ITZ	Interfacial Transition Zone
K ₂ O	Potassium Oxide
Kg	Kilogram
Kg/m ³	kilogram per cubic meter
L	Length
M	Meter
M ³	Cubic Meter
Mm	Millimeter
MPa	Mega Pascal
Na ₂ O	Sodium Oxide
OPC	Ordinary Portland cement
PFA	Pulverized Fuel Ash
SC	Share Company

SSD	Saturated surface dry
Vol.	Volume
W	Width
W/C	water to cement ratio
Wt.	Weight

CHAPTER 1 INTRODUCTION

1.1 General

Aggregates are one of non-renewable construction materials that are continuously being prone to rapid depletion. In order to produce construction materials with the same level of quality, strength, and durability engineers and researchers are forced to identify and come up with alternatives. Given that it occupies about 70 – 80 % of the volume of concrete and is one of the most crucial component, coarse aggregate has a significant influence on the characteristics and qualities of concrete. But the demand for this specific building material is difficult to provide because of urbanization and the rapid rise in population, especially in a nation like Ethiopia. Semere [1] stated that the construction activities in Addis Ababa and other cities of Ethiopia is growing from time to time .This shows the high demand of construction materials ,which include lacks for the production of aggregate. The supply-demand gap of aggregate is still imposing negative impact to the existing construction activities. This shows the importance of identification of potential resources and future planning. Hence, to overcome this problem one solution could be by using waste products such as waste ceramics tiles [2, 3].

Ceramic industries and construction sites produce wastes in different amount. These wastes in Ethiopia are not recycled in any form at the present. As the ceramic waste is piling up every day, there is a pressure on ceramic industries to find a solution for its disposal. Crushed ceramic aggregate can be used to produce concrete, without affecting strength [2, 3].

1.2 Statement of the Problem

Concrete is the most commonly used construction material in the world. The prices of cement and aggregate, which are the ingredients to make concrete, have increased as a result of this continuous demand of concrete structures. The extensive use of concrete has resulted in a high aggregate consumption rate .The depletion of natural aggregate for use by the future generations would result from continued use of this non-renewable resource.

Every production system generates waste products and by-products, which have impact on the environment. Despite the measures, the amount of industrial, construction, and demolition waste generated in Ethiopia is growing, which is contributing to the problem's

expansion. The need to manage these wastes has emerged as one of pressing issues of our time, necessitating specific measures intended to minimize waste production. During manufacturing and construction, the production of ceramic waste tiles are inevitable.

The ceramic wastes have been dumped and stacked at manufacturing factories and various construction sites, posing a significant problem for disposal, because they are piling up every day in Addis Ababa and other parts of Ethiopia. Rather than just using it as chips to decorate a floor or wall surfaces, these ceramic wastes could be used as coarse aggregate. Therefore, there has to be done more research in Ethiopia on the use of ceramic tiles as coarse aggregate to entirely or partially replace the conventional coarse aggregate for concrete production. Using recycled ceramic materials as a coarse aggregate has several benefits from sustainable and green concrete production perspectives.

In general, the following points serve as the primary drivers for the necessity to substitute waste ceramic aggregate with coarse aggregate:-

- Eco-friendly nature of ceramic aggregate concrete for green concrete production.
- Lack of awareness of using ceramic waste as alternative substitution for aggregate and ,
- The unbalance increase in price, supply and demand of aggregate in Ethiopian construction sector.

1.3 Research Questions

Questions that need to be answered are:

- i. Do ceramic tile waste coarse aggregate improve the strength of concrete?
- ii. What are the effects of ceramic tiles coarse aggregates on the physical and mechanical properties of Concrete?

1.4 Objectives of the study

1.4.1 General objectives

The objective of this study is to explore the potential for using ceramic waste tiles as a partial replacement of conventional coarse aggregate for cement concrete production.

1.4.2 Specific Objectives

The Specific objectives are:

1. Evaluating the mechanical and physical characteristics of crushed waste ceramic to be used as a coarse aggregate.
2. Investigating the influence of incorporating crushed ceramic waste tiles on fresh concrete properties such as workability (determined using slump measures) and fresh concrete density.
3. To determine how waste ceramic tile affects concrete's hardened properties (hardened density, compression strength, split tensile strength and flexural strength) in different percentage of ceramic tiles substitution of ceramic waste (10%, 20%, and 30%) for C20 and C25 concrete grade.
4. To make conclusion and recommendations based on the laboratory test results when the crushed ceramics are partially used to substitute the coarse aggregate.

1.5 Scope of the research

The study is limited to a material lab-based investigation of workability, density, compressive strength, and split tensile strength of concrete with increasing replacement levels of ceramic waste coarse aggregate while lowering the natural coarse aggregate.

1.6 Limitations

The objective of this study is to evaluate the possibility of improving the physical and mechanical characteristics of concrete both in its fresh state and hardened state, in particular, density, compressive strength, flexural strength and split tensile strength by partially substituting waste ceramic aggregate for conventional coarse aggregate at replacement levels of 10%, 20% and 30%, and comparing the results with the reference concrete. However, there was no appropriate equipment for crushing and screening ceramic waste, so successive crushing and sieving is required to obtain a uniform ceramic aggregate and produce the necessary amount of ceramic aggregate. Each piece of ceramic aggregate had to be crushed by hand, which was a back-breaking process. The tiles were manually crushed with a Ball-peen hammer into a variety of fragments, mostly with coarse aggregate sizes between 4.75 mm and 19mm.

To achieve a mix of tile fragments within the desired range, the ceramic tiles were crushed using the aforementioned method. Each tile was broken with an average of about 150

strikes using a Ball-peen hammer, creating other small wastes that are unusable for the intended purpose. The resulting fragments differ from the natural aggregate in that they are less cubical or spherical and more angular. Therefore, in order to produce a significant amount of ceramic aggregates a crushing machine has to be considered for future studies.

Additionally, it was challenging to find the most recent information on the amount of waste ceramics disposed of in and out of Addis Ababa and other regions of Ethiopia.

1.7 Significance of the study

Aside from the erratic nature of Ethiopia's construction activities, the production of concrete is crucial and a must. Because of this, which make up the majority of concrete, aggregates are in high demand. Due to the rapid depletion of natural aggregates in nation like Ethiopia, surface extractions disrupts the biological balance in addition to destroying the landscape. In order to ensure the production of concrete in the future, a new source of aggregates must be identified and used properly. The ceramics waste coarse aggregate enables to achieve two main objectives, first, it could help preserve the environment by reducing piles of wastes and second, it can assist the concrete attain the required strength. The research help in the advancement of utilization of ceramic waste coarse aggregates as a construction material for concrete production heading forward, because it is becoming necessary for alternative sources of aggregates.

1.8 Research Methods

The research methods used are laid out in a way that it can address the general and specific objectives of the project. The following methods have been employed in order to achieve the objectives:-

- i. Literature review, which includes ceramic wastes, natural aggregates and concrete both in fresh and hardened state. The review includes books, journals, and research papers.
- ii. Preparation of ceramic waste samples in different percentage of natural coarse aggregate replacement (Includes crushing, sieving and blending).

- iii. Performing laboratory tests for the concrete making ingredients and the concrete itself. In order to have better understanding of the study area intense desk study has been conducted about properties of concrete and concrete making ingredients .
- iv. Analyzing, discussion and interpretation of the test results in are made in graphical and tabular form.
- v. Finally, conclusion and recommendation based on the results obtained are formulated.

1.9 Structure of the thesis

The research is organized into six main chapters and each chapter contains a number of sections and further subsections. Chapter one gives a general introduction, briefly describes the background of the project, statement of the problem, research questions, objectives of the project, scope of the project, limitations and significance of the study. In chapter two, a compressive review about previous relevant research works and effort on the utilization of ceramic waste material in concrete making are presented. Chapter three describe the methodology and properties of materials used. Chapter four explains about the experimental program, the mix proportions, mixing, casting, curing, and procedures used in the attempt to find out in a systematical and scientific study. Chapter five presents the results and discussions in the form of graphs and tables associated with some photos. Chapter six covers the conclusions of the study, recommendations for future studies, and the contribution to the knowledge when crushed ceramic tiles are used as a partial replacement of coarse aggregate in cement concrete making.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter is based on an analysis of related research that has been conducted in the area of producing concrete from ceramic wastes, both theoretically and empirically. In order to support the research study's contribution to knowledge, a summary of the relevant literature is also provided. This chapter provides an understanding of the research problem by making references to earlier concepts, theories, and studies associated with this particular field of study.

The use of sustainable building materials is spreading throughout the world as environmental preservation becomes a major social concern. However, the use of construction wastes in the production of new sustainable concrete is not a recent area of research. According to historical evidence, Romans frequently used waste materials from construction and demolition to build roads [2].

Utilizing waste materials from construction and demolition, like ceramic tiles has been shown to benefit the environment both during production and use, offering a greener and more long-lasting solution. Natural resources (such as gravel pits and rock quarries) can be preserved by using various wastes as aggregate when creating new concrete, which can eliminate other related manufacturing processes like excavation / blasting, transportation, crushing, etc. The demolition waste that results from tearing down an old building must also be dumped in landfills. Since Nie [4] noted, "For the resource extraction, manufacture, application and disposal of materials, numerous resources and energy are consumed, and environment deterioration occurs with the inputs and outputs of various raw materials, energy, by-products, and wastes, " this process entails the cost of material handling, dumping, and transportation. The amount of waste used for construction and demolition will significantly reduce landfill usage.

Since concrete is a key component of many different structures, extensive research has been done on it to improve its properties in every way possible and create a mass of concrete that is sustainable. The only way to strengthen concrete is to swap out its existing components for better ones. Environmentally friendly materials are also more appropriate for construction when they are used in addition to replace the materials. The use of ceramic

tile aggregate in concrete, a waste product directly from industry or indirectly from the demolition of a structure in different countries, has been the subject of numerous studies in this regard.

2.2 Concrete

One of the most important man-made building materials in the world is concrete. Concretus, which means "to grow together" in Latin, is where the word "concrete" originates. Concrete is a compound made of various components, including coarse granular material (aggregate) embedded in a hard matrix of material (cement or cementitious materials), which fills in the spaces and binds the aggregate particles together. Concrete is also referred to as a building material that primarily consists of a binder that contains fine or coarse aggregate particles or fragments. Sand serves as the fine aggregate, hydrated cement serves as the binder, and the final product is concrete [5].

A variety of ground-breaking materials in the field of concrete technology have been produced recently in response to the construction industries' ongoing need to meet functional, strength, economic, and durability necessities. Concrete is the substance that is used the most in the world. Construction of private buildings and infrastructure are both significantly impacted [6].

A fresh concrete mix's consistency, or workability, is one of the fundamental characteristics of concrete. It should be able to be compacted easily using the right technique without requiring excessive effort. Workability is the ease with which concrete can be compacted, but it would be oversimplifying to say that it also has an impact on placement simplicity and resistance to segregation. Additionally, the available compaction techniques would determine the desired workability in any given circumstance; similarly, the workability required for mass concrete is not always adequate for thin, inaccessible, or heavily reinforced parts. Workability of the concrete depends on a number of interrelating factors, such as water content, aggregate properties, use of admixtures and fineness of cement are some of the factors [5, 6].

Consolidation is necessary to arrive at such a definition. The process is fundamentally the same whether the concrete is compacted by ramming or vibration: the air that has been trapped in the mixture is released until the concrete has reached the configuration that is optimal for the mix. The work done as a result is used to lessen friction between individual

concrete particles as well as between the concrete and the surface of the mold or reinforcement [5].

There are two types of friction: internal friction and surface friction. Additionally, some of the effort goes into vibrating the mold, the shock, as well as the fully cured concrete. The task was thus accomplished. Adequate strength and durability are the fundamental requirements for hardened concrete. Concrete's strength is frequently considered to be its most crucial characteristic and is used to judge its quality. As the final factor in structural design, this is crucial [5].

2.2.1 Constituent Materials for Making Concrete

Concrete is made composed of cement, fine aggregates, coarse aggregates, water, and occasionally admixtures. In order to create a solid, homogenous concrete, the components are combined until a cement paste formed, filling in the majority of aggregate voids. Once the plastic concrete has had enough time to cure, set, and gain sufficient strength, it is then poured into a mold. For a better knowledge of the attributes and performance of concrete, it is crucial to understand the properties of the basic ingredients of concrete mixtures, such as aggregates, cementitious materials, admixtures, and water [6].

a) Cement

A material that is used to make concrete called cement is described as having components that bind together to increase the strength and durability of the concrete. A material that binds other substances while also setting and hardening independently is cement. The four primary raw materials used to make cement are alumina, iron oxide, silica from shale, and lime from limestone. Clinkering is the process of heating limestone to 1450 °C in a kiln with trace amounts of other raw materials to create a clinker for cement manufacturing. In order to create regular Portland cement, the product is then cooled and ground into a fine powder. Portland cement is the most widely used type of cement [5].

b) Aggregates

About three-quarters of the volume of typical concrete is made up of aggregates, which are the building blocks of concrete. A component that makes up such a large portion of the mass is therefore bound to contribute important qualities to both the fresh and hardened

product. Aggregate is regarded as an inert dispersion in cement paste. The performance of concrete can be impacted by the physical, thermal, and chemical properties of aggregate, so it is not completely inert [5].

c) Water

Because water is such a crucial component of concrete, a properly-constructed concrete mixture, which normally comprises 15 to 25% water by volume, has the requisite workability for fresh concrete as well as the necessary durability and strength for hardened concrete. Hydration is one of water's key benefits. Two of the most important aspects in the creation of top-notch concrete are the total amount of water in the concrete and the water-to-cement ratio. Because too much water weakens concrete and too little water renders concrete unworkable, the amount of water used in concrete mixing must be balanced. Concrete must be both strong and workable, so the ratio of water to cement and the overall volume of water must be carefully determined [5, 6].

2.2.2 Mechanical characteristics of concrete

a) Fresh concrete characteristics

Density of fresh concrete

Fresh concrete density, also referred to as unit mass or unit weight in air, can be calculated experimentally using ASTM standard C138-09. By dividing the total mass of all the materials used to make a batch of concrete by the volume that the concrete filled, the density of the mixture is determined. On the other hand, you can calculate the yield per batch by dividing the mass of all the components in a batch by the density of fresh concrete if you know it [5].

Workability

Workability is defined as the ability of concrete to be easily compacted, but to simply state that workability determines placement ease and resistance to segregation is insufficient to describe this crucial concrete property. Furthermore, the desired workability in any given situation would depend on the available methods of compaction; similarly, a workability suitable for mass concrete is not necessarily acceptable for thin, inaccessible, or heavily reinforced sections. Due to these factors, workability should be regarded as a concrete property without consideration of the specifics of a particular type of construction [5].

It is necessary to think about what occurs when concrete is being compacted in order to arrive at such an explanation. Whether by vibration or by ramming, the process of compaction essentially involves removing trapped air from the concrete until it has reached the closest configuration possible for a particular mix. As a result, the work is used to lessen resistance between the surface of the concrete and the surface of the mold or the reinforcement as well as between the concrete and the concrete itself. These two have two different names: internal friction and surface friction. In addition, some of the work done is used in vibrating the mold or in shock and, indeed, in vibrating those parts of the concrete which have already been completely consolidated [5].

b) Hardened concrete characteristics

Due to the fact that this experiment is engaged to check the concrete's strength for quality assurance or acceptance, a standard test cylinder or cube is compressed to determine the uniaxial compression strength of the concrete, which is referred to as concrete strength. Other strength parameters, such as tensile and bond strength, are expressed relative to compressive strength for convenience [5].

Compressive Strength and Split Tensile Strength

Hardened concrete testing verifies the concrete's quality and workmanship. The test method should be simple, straightforward, and straightforward to carry out. To predict the compressive strength of concrete, compression tests can be performed on cubes and cylinders. It should be noted that a standard compression test specimen only specifies the concrete's potential strength, not the concrete structure's strength. The recommended cube specimen size for a 20 mm maximum aggregate size is 150x150x150 mm, and compressive strength is determined by ultimate load per unit area. Typical failure of specimens is represented in figure 2.1 below [5].

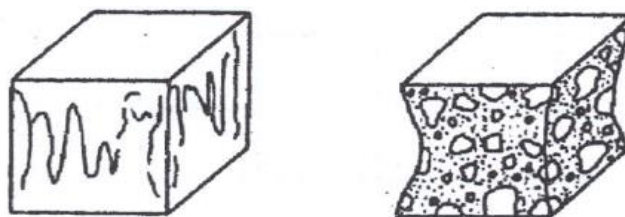


Figure 2.1 Typical compression failure of cube samples [5].

The cylindrical specimen used to measure split tensile strength is 150x300 mm in size. The cylindrical specimen will be properly capped before being tested. Cylindrical compressive strength is typically 75-85% of cube strength. The cylinder, on the other hand, appears to be less affected by the end of restraints caused by platens, and thus appears to produce more uniform results than the cube specimen [5].

The split tensile method is a well-known indirect method for determining concrete tensile strength. The test involves applying compressive line loads to the opposite generators of a concrete cylinder placed between the platens with its axis horizontal. According to the elastic analysis, the applied line loading induces a fairly uniform tensile stress over nearly two-thirds of the loaded diameter. Tensile stress is computed using equation 2.1 below [5].

$$F_{ct} = \frac{2P}{\pi DL} \dots\dots\dots (Eq 2.1)$$

Where F_{ct} – tensile stress, P- is the compressive load, D - is diameter of the cylindrical specimen and L- is the length of cylinder specimen.

Flexural Strength

Flexural strength, also known as bending strength, or transverse rupture strength, is a material property, defined as the maximum stress in a material just before it yields in a bending test. In this test, a bending moment is applied to the specimen, and a bending force is applied downward on a member that is only supported at its two ends. Compressive stresses are generally developed above the neutral axis, while tensile stresses are developed below the neutral axis [5].

According to ASTM C 78, third point loading is used to test the flexural strength of concrete beams, with half of the load applied at each third of the span length. The ends of the concrete beams are supported, and their interior locations are loaded as shown in figure 2.2 below [5].

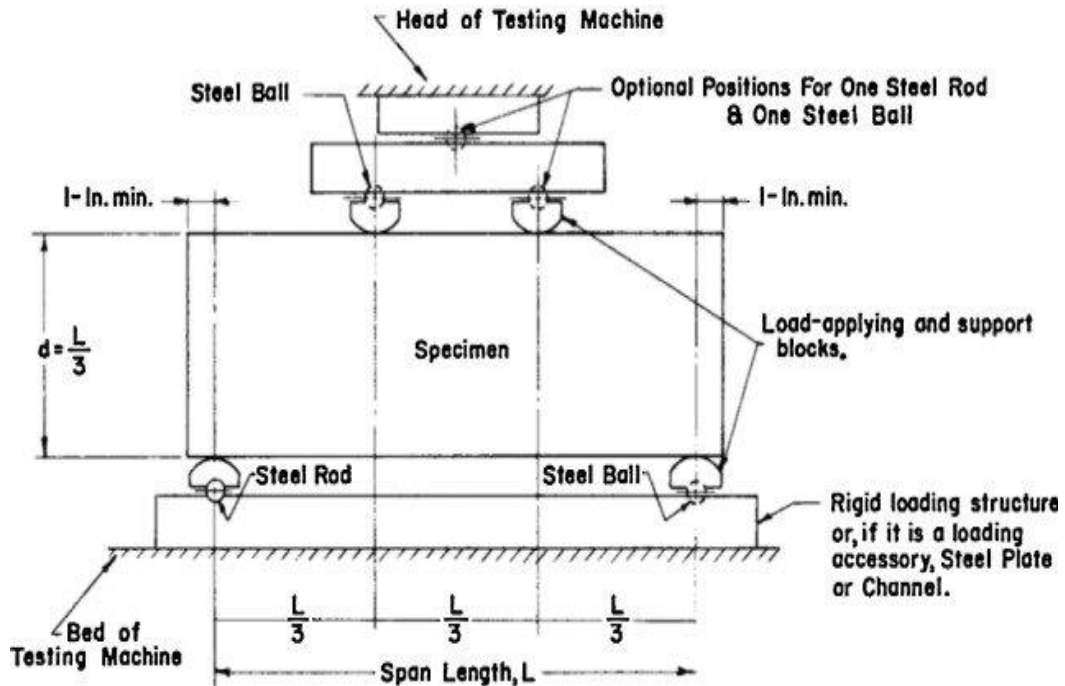


Figure 2.2 Standard Test Method for Flexural Strength of Concrete [5].

2.3 Aggregates

The term "aggregate" refers to the group of mineral components, such as sand, gravel, and crushed stone, that are combined with a binder (such as water, bitumen, Portland cement, lime, etc.) to create compound materials (such as asphalt concrete and Portland cement concrete). For both flexible and rigid pavements, aggregate is also used for base and sub base courses. Natural or artificial aggregates are both acceptable. In general, larger rock formations are excavated openly to obtain natural aggregates (quarry). Mechanical crushing is typically used to reduce extracted rock to sizes that are usable. Aggregate that has been manufactured is frequently a byproduct of other manufacturing sectors [5, 7].

Fine and coarse aggregates make up 65 to 75 percent of the volume of concrete and are crucial ingredients in the production process. The two types of aggregates are fine and coarse aggregates. Natural sand that has been graded from 4.75 mm to the smallest particles and excludes dust is commonly referred to as fine aggregate. Coarse aggregate is defined as natural gravel or crushed stone that is larger than 4.75 mm [8].

2.3.1 Materials for Aggregates

The type, quantity, and bond between paste and aggregate, as well as the cement paste properties affect the compressive strength of concrete. These, in turn, are influenced by macro- and microscopic structural characteristics, such as overall porosity, pore size and distribution, structure, and function of hydration products, and the connection between different concrete specimens, all of which need to be taken into account [8]. Other concrete properties, like durability and abrasion resistance, are also greatly influenced by the aggregate, which is in turn influenced by the parent rock's strength, purity, surface roughness, and other factors. In light of the aforementioned, aggregate materials are added to concrete to improve its thermal properties, impact and sound absorption, chemical resistance, strength, volume, and durability [7]. They are also used to decrease creep, shrinkage, and overall cost.

A variety of materials are used as aggregate, including ceramic tiles, palm kernel shells, pumice, crushed rock, recycled concrete, gravel, scrap iron, lead, iron shots, barites, and crushed burnt bricks. Almost any material that is readily available and satisfies a few minimal criteria can be used as aggregate for concrete. [7] Stated that when choosing aggregate for typical structural concrete, it's important to take into account factors like cleanliness, hardness, cost, chemical inertness, availability in required sizes and good form, availability in required grading, and availability in good surface textures. Since they have an impact on both the concrete and the mortar, the primary characteristics, such as cost, workability, strength, and durability, are very important.

2.3.2 Functions of Aggregates

Aggregates serve three main purposes: (1) to provide a relatively inexpensive filler for the cementing material; (2) to provide a mass of particles suitable for resisting the action of applied loads, abrasion, moisture percolation, and weather action; and (3) to reduce the volume changes brought on by the setting and hardening process as well as from moisture changes in the cement-water paste [7].

2.3.3 Grading of Aggregates

Because the quantity of voids among aggregate particles demands the same amount of cement paste to fill out in the concrete mixture, grading defines the paste needed for a

practical concrete. Sieve analysis is required to obtain a grading curve for an aggregate. Aggregate makes up around 75% of the volume of concrete. Aggregates come in two forms: divided and all-in aggregates. Divided aggregate is the one that comes in different sizes. All of the different sizes of particles are contained in one sample of aggregate, and if the grading is good enough, it can be used to make concrete [5, 8].

a) Fine Aggregate Grading

Natural sand or broken stone with most particles less than 4.75 mm make up fine aggregates. Table 2.1 displays the fine aggregate grading limit for various sieve opening sizes according to Ethiopian standard (ES C.D3.201).

Table 2.1 Grading Requirement for Fine Aggregate (ES C.D3.201)

Percentage passing through test sieves having square openings						
9.5mm	4.75 mm	2.36 mm	1.18 mm	600µm	300µm	150 µm
100	95-100	80-100	50-85	25-60	10-30	2-10

b) Coarse Aggregate Grading

The Ethiopian standard (ES C.D3.201) for coarse aggregate grading as shown in table 2.2 below provide a range of grading and grading sizes. If the proportion of fine aggregate to total aggregate creates concrete with adequate workability within a reasonable range, the grading for a specific maximum size coarse aggregate can be changed not affecting the cement and water requirements of a mixture. If the coarse aggregate grade varies greatly, the quantities of the mixture should be modified to make workable concrete. Because changes are difficult to predict, maintaining uniformity in the manufacturing and processing of coarse aggregate is frequently more cost effective than reducing gradation variations. The largest size of coarse aggregate accepted for use in concrete has an impact on concrete economy [5].

Table 2.2 Grading Requirement for Coarse Aggregate (ES C.D3.201).

Nominal size of aggregate ,mm	Percentage passing through test sieves having square openings						
	75mm	63mm	37.5mm	19mm	13.2mm	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

2.3.4 Classification of Aggregate

In concrete, aggregate was employed as an inert filler. The aggregate is not an inert filler, and its physical, thermal, and chemical qualities have a significant impact on the concrete's performance. Because aggregate is less expensive than cement, it is more cost effective to use as much aggregate as possible and as little cement as possible, but cost is not the only rationale for utilizing aggregate in concrete. Aggregates are classified based on the following categories [7].

a) Based on Sources

i. Natural Aggregate

These are acquired by crushing igneous, sedimentary, or metamorphic rocks in quarries. Gravels and sand that have been decreased in size by natural forces also come into this group. Igneous aggregates are the most commonly utilized aggregate. The majority of the time, aggregates acquired from pits or dredged from a river, creek, or sea are not clean or properly graded enough to meet the quality requirements [8]. There are various rock types when crushed are suitable for used as aggregates. These include;

- **Sedimentary rocks:** The accumulation or deposition of mineral or organic particles at the Earth's surface, followed by cementation, produces sedimentary rocks like limestone. Sedimentation refers to the processes that lead to these particles settling in one location. [6, 9].
- **Igneous rocks:** Magma, which is a molten rock, is the source of igneous rocks. They are typically exceedingly difficult to break since they are primarily crystalline (consisting of interlocking crystals). The most prevalent rock types are granites, basalt palates, and gabbro. Because they are robust, thick, and granitic, they are popular because they cling to cement nicely [6, 9].
- **Metamorphic rocks:** Metamorphic rocks began as another type of rock, but have undergone significant transformations from their original igneous, sedimentary, or metamorphic state. When rocks are exposed to intense heat, high pressure, hot mineral-rich fluids, or a combination of these elements, metamorphic rocks form. These kinds of conditions can be found deep within the Earth or where tectonic plates collide. Marbles and quartzite are some of the example this kind of rocks [7, 8].

ii. Artificial Aggregates:

These are made primarily from industrial trash, waste materials, and occasionally natural resources. Artificial aggregate manufacturing plants, on the other hand, are presently in operation. These aggregates are typically utilized in lightweight or heavy-weight concrete, or where a useful use for an industrial by-product is desired. The majority of them are lightweight aggregates. Some artificial aggregates, such as cinder, blast furnace slag, sintered glass aggregate, and so on, are byproducts of unrelated industrial processes. Artificial aggregates include broken bricks, blast furnace slag, and synthetic aggregates. Brick bats, or broken bricks, are ideal for mass concreting, such as foundation base. They are not employed in the construction of reinforced concrete structures. Blast furnace slag aggregate is made by slowly cooling the slag and crushing it. Precast concrete products are made from the dense and strong particles obtained. The specific gravity of these range between 2.0–2.8 and bulk density 1120–1300 kg/m³ [9].

b) Based on Density

- i. **Heavy Weight Aggregate:** These are aggregates with specific gravity of 4.0 and above, these include scrap iron, ball bearings, ilmenite magnetic and barites. They are mainly used in concretes which require high density such as in radiation shielding in nuclear power plants and for concrete weight. The density of heavy weight concrete is more than 3600kg/m³. Steel shots can produce concrete of about 7000 Kg/m³ density [9].
- ii. **Light-Weight Aggregate:** They are used to produce low density concretes which are advantageous in reducing the self-weight (dead loads) of a structure. They have better thermal insulation than normal weight aggregates. The reduced specific gravity is obtained from air voids within the aggregate particles. These aggregates have specific gravity usually less than 2.6 and an oven-dry density range between 500 to 2000kg/m³ (BS 812-101, 1990) these aggregate have high porosity, which result in low apparent specific gravity. Most artificial aggregates, such as sintered PFA and foamed slag, belong into this group. Pumice is an example of a natural lightweight aggregate. It is a low-density volcanic rock that occurs naturally. It has been around since the Roman era. They all result in a reduction in concrete strength due to their decreased specific gravity and greater porosity. Because lightweight particles are less stiff than regular aggregates, concretes with higher elastic modulus, creep, and shrinkage are produced. Type, source, and whether lightweight fines or natural sand are used all influence the strength properties of lightweight aggregates.

- iii. **Normal - Weight Aggregate:** Many natural aggregates are from granites, gravels, basalts, and limestone's etc. fall under this category. All these aggregates have specific gravities within the range of 2.55 to 2.75 and therefore they produce concretes with similar densities, normally in the range of 2200 - 2450 Kg/m³ depending on the mix proportions. These are used for making normal structural concrete. Normal weight aggregate should meet the requirement of BS 812- 2 (1995).

c) Based on Particle Size

Aggregate particles come in a variety of sizes, with the typical aggregate particle size being 20 mm. The maximum aggregate particle size used in concrete is almost between 10 mm and 50 mm. Grading describes the distribution of particle sizes. Low-grade concrete may be made with aggregate from deposits containing a whole range of sizes, from the largest to the smallest, known as all-in or pit-run aggregate. When making high-quality concrete, the option, which is much more prevalent and always used, is to purchase the aggregate in at least two separate lots, with the main division being at the size of 4.75 mm or Number 4 ASTM sieve. This divides fine aggregate sand, from coarse aggregate [5].

- **Coarse Aggregate:** Coarse aggregates are those that are mostly retained on a No. 4 (4.75 mm) screen. The size of coarse aggregate typically ranges from 5 to 150mm.

The maximum size of coarse aggregate in typical concrete used for structural components such as beams and columns is roughly 25 mm. The greatest size of mass concrete used for dams or deep foundations might be as large as 150 mm.

- **Fine Aggregate:** Aggregates passing through a No. 4 (4.75 mm) sieve and predominately retained on a No. 200 (75 µm) sieve are classified as fine aggregate. River sand is the most commonly used fine aggregate. In addition, crushed rock fines can be used as fine aggregate.

d) Based on Shape and Texture

The shape of aggregate is an important characteristic since it affects the workability of concrete. The shape of the aggregate is very much influenced by the type of crusher and the reduction ratio, i.e., the ratio of the size of material fed into crusher to the size of the finished product. Particle shape and size distribution influence the water content

necessary to obtain a mix of suitable resistance, and then by affecting the compressive strength, drying shrinkage and durability of the resulting concrete [7].

The quality of aggregates known as surface texture is determined by how polished or dull, smooth or rough the particle surfaces are relative to one another. The extent to which forces acting on the particle surface have smoothed or roughened it varies on the hardness, grain size, pore structure, rock structure, and surface texture. Additionally, tests have demonstrated that rough – textured aggregate produces greater binding strength in tension than smooth – textured aggregate [6, 7].

When it comes to the properties of fresh and cured concrete, the exterior characteristics of the aggregate, particularly the shape and surface roughness, are critical. The properties of freshly mixed concrete are influenced by particle shape and surface roughness more than the qualities of cured concrete. Smooth, rounded, and compact aggregate require more water to form workable concrete than rough-textured, angular, and elongated aggregate. To maintain the water-cement ratio, the cement content must be raised as well. Flat and elongated particles are often avoided or limited to roughly 15% of the total aggregate weight. The most important criteria for a concrete aggregate is that it stay stable within the concrete and in the specific environment throughout the duration of the concrete's design life, without impacting the concrete's performance in either the fresh or hardened condition [9].

In general, the shape influences the properties of fresh concrete more than when it is hardened. Rounded aggregate are highly workable but yield low strength concrete. Same is the case with irregular shaped aggregate. Flaky aggregate require more cement paste, produce maximum voids and are not desirable. Angular shape is the best. Crushed and uncrushed aggregates generally give essentially the same strength for the same cement content. The shape and surface texture of fine aggregate govern its void ratio and significantly affect the water requirement [9]. Table 2.3 below provides a suitable technique of classifying particle shape [5].

Table 2.3 Shape and texture of aggregates [5].

Classification	Description	Examples
Rounded	Fully water worn or completely shaped by attrition	River or seashore gravel ,desert, seashore and windblown sand
Irregular	Naturally irregular , or partly shaped by attrition and having rounded edges	Other gravels ,land or dug flint
Flaky	Material of which the thickness is small relative to other two dimensions	Laminated rock
Angular	Possessing well defined edges formed at the intersection of roughly planar faces	Crushed rock of all types ,crushed slag
Elongated	Material usually angular , in which the length is considerably larger than the other two dimensions	
Flaky and elongated	Material having the length considerably larger than the width ,and width considerably larger than thickness	

2.3.5 Mechanical characteristics of aggregates

Given that aggregate makes up 65 to 75 % of the volume of concrete, it's impossible to overstate the importance of knowing its physical and chemical properties. Several typical aggregate physical qualities are relevant to aggregate behavior in concrete and concrete properties made with the particular aggregate [8].

a) Bond of aggregate

The nature of the link between aggregate and cement paste is a key aspect in concrete strength, particularly flexural strength, but it is not well understood. The interlocking of the hydrated cement paste and aggregate is partially a result of the surface properties of the aggregates. Due to mechanical interlocking, a rougher surface, such as that of crushed particles, produces a stronger bond; softer, porous, and mineralogical diversion of particles

also usually result in a better bond. Texture qualities that prevent penetration of the particle surface are often not favorable to successful bonding [5]

The evaluation of aggregate bond quality is challenging, because there are no standardized tests. A crushed specimen of normal strength concrete should, in general, besides the more abundantly ones that were pulled out, comprise some aggregate particles that were broken through immediately of their sockets. However, an overabundance of fragmented particles could indicate that the aggregate is excessively weak [5].

b) Strength of aggregate

Although it is difficult to determine the strength of individual particles, Concrete's compressive strength cannot significantly exceed that of the majority of the aggregate it contains. Consequently, evaluating each aggregate's ability to withstand crushing particles is challenging, so the necessary information is typically determined through indirect tests, such as the crushing value of bulk aggregate, the force needed to compact bulk aggregate, and the performance of aggregate in concrete. [5].

When the concrete specimen is crushed, the aggregate strength will be lower than the nominal compressive strength of the concrete mix if it reduces the compressive strength of the concrete, particularly if numerous individual aggregate particles are visible fractured in which the aggregate was incorporated. Clearly, such aggregate can only be used in low-strength concrete [5].

2.3.6 Physical Properties of Aggregates

a) Specific gravity

The specific gravity of a material is the ratio of the substance's unit weight to that of water. The word specific gravity, when applied to aggregates, usually refers to the density of the individual particles rather than the aggregated mass as a whole. In order to calculate concrete mix proportions, it is necessary to determine the spaces occupied by aggregate particles within the relatively thick cement paste, independent of whether the particles include pores or internal voids. As a result, the bulk specific gravity of the particles can be calculated. The weight in air of a particular volume of a substance at standard temperature divided by the weight in air of an equivalent amount of distilled water at standard temperature is the bulk specific gravity. The bulk specific gravity of saturated surface dry

aggregates is always measured for use in concrete mix calculations. A variety of regularly used aggregates have specific gravities 2.6 – 2.7 that fall within this range [5, 7].

b) Bulk density

It is well known that a material's density in the metric system is mathematically equivalent to its specific gravity, despite the fact that the specific gravity is a ratio whereas density is described in kilograms per cubic meter. Because when aggregate is batched by volume, it is necessary to know the bulk density, which is the actual mass that would fill a container of unit volume. This density is used to convert quantities by volume because it is physically impossible to pack these particles so tightly that there are no voids between them. [5].

The actual bulk density of aggregate is determined not only by the material's numerous qualities, which influence the potential degree of packing, but also by the actual compaction achieved in a particular case. The densest packing, for example, is attained when the centers of spherical particles of the same size lie at the apexes of imaginary tetrahedral [5].

c) Surface moisture ,Porosity and absorption of Aggregate

The different states in which an aggregate can exist in terms of moisture content are: (1) oven dry (2) air dry (3) Saturated, dry surface and (4) Damp, or wet surface [7].

It's worth noting that if the aggregates are dry, if the aggregates possess surface moisture, they add too much water to the mix, raising the water to cement ratio; otherwise, they take up water from the mixing water, lowering workability. Both of these situations are detrimental to concrete quality. Corrective steps for both absorption and free moisture should be done while constructing quality concrete so that the water/cement ratio is kept as close to the design as possible [5].

The entire water contained in the aggregate in the saturated surface-dry state is represented by absorption, and the water in excess is represented by surface moisture (or free moisture). The sum of absorption and surface moisture content determines the overall water content of a damp or moist aggregate. The free moisture content of the surface or free aggregates is usually expressed as a percentage of the weight of the saturated surface dry aggregates [5].

One of the most important elements influencing the qualities of both fresh and cured concrete is the porosity of the particles. Porosity refers to the number of voids in a solid particle. From 0% to 100%, it is expressed as a percentage of total volume. Concrete with a higher porosity of aggregates has a poorer strength and durability. The porosity of aggregate is crucial because it influences the bulk specific gravity, permeability, and absorption of the aggregate, all of which influence the qualities of the final concrete. Because of its viscosity, the surface pores are regarded impervious to cement paste unless their apertures are very large [5].

2.4 Green Concrete

For more than 2000 years, concrete has been used in building. Concrete has gained popularity in the construction industry due to its dependability and durability. Beyond construction, concrete's role in advancing society, the economy, and the environment is frequently overlooked.

It was discovered that concrete structures perform better in terms of energy than steel ones. Concrete constructions are not only affordable but also flexible in their design. Concrete constructions are also more environmentally friendly than steel or aluminum ones [10].

Researchers are constantly working to improve the sustainability and environmental friendliness of the concrete industry, and they came up with the concept of green concrete (recycled concrete). A sustainable type of concrete such as "green concrete" and "recycled concrete" are produced using substitute aggregates like recycled aggregate concrete, rubber tires, ceramic waste tile, glass aggregate, etc. It might also be the result of waste material admixtures, such as leftover latex paint, or Portland cement replacements like fly ash, silica fume, and slag. Green concrete can therefore lower the cost of producing concrete and has less of an impact on the environment in terms of energy use and emissions during its manufacturing process [11].

2.5 Green concrete and sustainability

A sustainable material is frequently described as one that benefits the environment both during production and use. However, there are other factors besides environmental advantages that characterize a sustainable material. Before a material is deemed sustainable, social and economic benefits must also be taken into account. As a result, the

investigation of the green concrete's environmental, economic, and social benefits should offer a sustainable solution for reducing industrial and construction wastes [12].

The environmental benefits of using green concrete can be seen primarily in two ways. Firstly, the benefit of using any amount of ceramic waste aggregate would help limit the amount of industrial and construction wastes heading to landfills.

Ceramic waste aggregates are difficult to degrade and will stay in a landfills for a long time. This can keep the size of a landfills under control and lengthen their useful lives by reducing these waste materials. Additionally, using green concrete would help reduce the carbon footprint. The number of gravel pits and rock quarries can be decreased as well as the significant amount of greenhouse gases produced during the excavation and extraction of natural aggregates by using ceramic waste aggregates in new concrete. Our carbon-neutralizing ecosystems can be preserved by reducing the number of gravel pits and rock quarries [12].

The large costs associated with the extraction of natural aggregate (such as the stripping and blasting) are not present with waste aggregate. The use of ceramic waste aggregate from local landfills will also contribute to a reduction in high transportation costs currently incurred on the use of natural aggregate [13].

In some areas, the social advantages of using green concrete might not be as obvious as the economic or environmental advantages. Because of the potential for soil contamination, odors, increased traffic, and loss of land value, it is not advisable to have a landfill in a public area. Concrete can be made with waste ceramic as a coarse aggregate, which could help save landfill space. Additionally, local governments typically operate landfills and bear the associated costs. These savings could be invested in community enhancing social programs. The size of gravel pits being reduced may also have positive social effects.

Despite the fact that gravel pits frequently support local economies and create jobs, they have a negative impact on the local truck traffic. Increased truck traffic has the potential to harm communities by making roads more hazardous, shortening the lifespan of roads not intended for heavy traffic, compromising privacy, and generating noise and air pollution. As a result, communities may also see benefits from the elimination of gravel pits [14].

2.6 Ceramics

One of the oldest industries on the planet is the ceramics production sector. The Greek word *keramikos*, which means "potters" clay, is where the word "ceramics" originates. The majority of the natural materials used to create ceramic products are composed of clay minerals. These minerals acquire the distinctive qualities of fired clay after a controlled drying process and temperature firing between 700 °C and 1000 °C. An inorganic, non-metallic solid known as a ceramic is one that has been heated and then cooled. Ceramic materials can be amorphous, crystalline, or partially crystalline in structure (e.g. a glass). The definition of ceramic is frequently limited to inorganic crystalline materials as opposed to the non-crystalline glasses because the majority of common ceramics are crystalline. Pottery items, including 27,000-year-old figurines, were the earliest ceramics created by humans. They were made from clay, either by itself or when combined with other materials, and were then hardened in fire [15]. Later ceramics were fired and coated with glaze to produce a smooth, colored surface. Today, ceramics encompass a wide range of ceramic artwork as well as domestic, industrial, and building products. New ceramic materials were created in the 20th century for use in advanced ceramic engineering, such as semiconductors [16].

The crystalline ceramics are found to be resistant to a variety of processing, so they are created in the desired shape either by reacting on the spot or molding powders into the desired shape and then heating them until they solidify. Non-crystalline ceramics, on the other hand, are made from melts, and during this process, the glass is either formed when it has a viscosity similar to toffee or when it is in a molten state. Large amounts of ceramic waste are produced, particularly in large ceramic factories, ceramic product manufacturing facilities, and regular construction activities [16].

Traditional ceramics, which include bricks, roof and floor tiles, other construction materials, and technical ceramics like porcelain possess wide compositional range of the natural clays used as raw materials and this makes them highly heterogeneous [17].

2.6.1 Manufacturing process of ceramics

To understand the significance of the qualities of ceramic materials in the production of the ceramic article, it is necessary to take a brief look at the manufacturing processes. These vary depending on the kind of product produced as well as the techniques that the

intended shape and material's physical characteristics lend themselves to. The main steps are shown in figure 2.3 below; some of these steps might be unnecessary in some situations and necessary in others [16, 18].

However, products used at room temperature are frequently glazed, necessitating a second or Glost fire to develop the glaze and make it glow over the surface of the ware and attach to the body. For refractory items, firing is typically the end of the process. A second firing may be necessary for fine ceramic ware after ornamentation. When heavy clayware is coated in glaze, the intention is to make the surface impermeable rather than to enhance the aesthetic, as is the case with fine ceramics. If glaze had not been added, the porous material under the glaze in these products would easily absorb liquids, For instance, sanitary equipment and sewer pipes show how unacceptable this is. In general, heavy clay products are only burnt once. Either no glaze is applied as in the case of constructing bricks or the glaze is added after the body has been shaped and dried, with the same fire acting to mature both the body and the glaze [16,18].

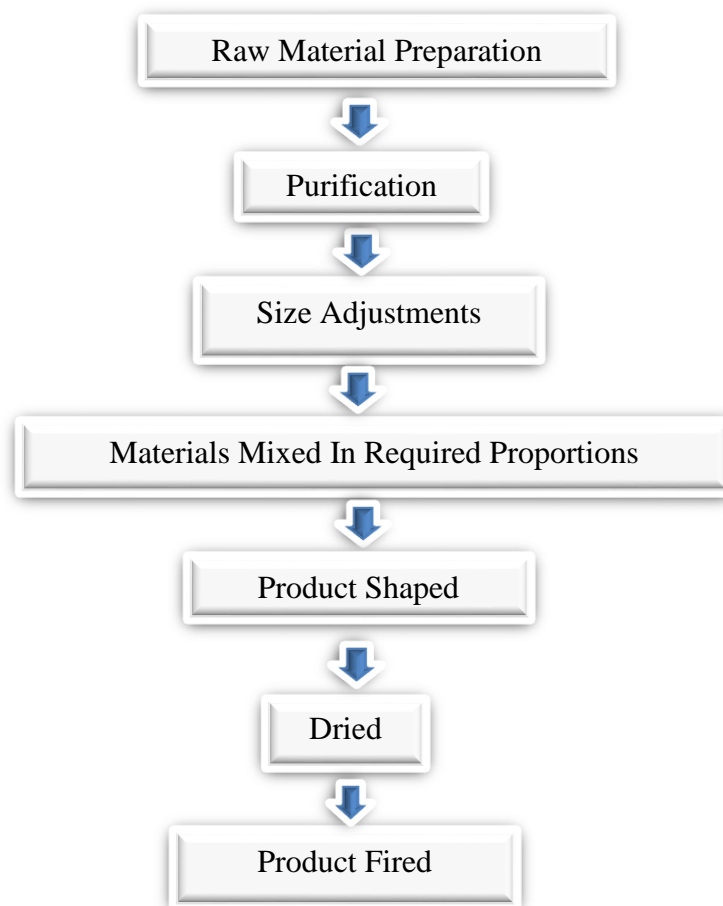


Figure 2.3 Ceramic manufacturing process [18].

2.6.2 Ceramic raw materials

The American Ceramic Society asserts that the firing of slurry, a semi-liquid clayey substance, marked the beginning of ceramic manufacturing. The glazing material was found in Egypt 5000 BC, and the earliest manufactured ceramic tile was found in India 14,000 BC. Around 1550 GC, furnaces were introduced into the production process to increase ceramics' resistance to high temperatures. Ceramic production advanced, leading to the realization of a variety of forms, uses, and qualities [19].

Despite using the same basic components, ceramic tiles have differences from one another. Each producer uses proportions that are nearly identical. All of these raw materials, which include the following natural resources:

- Potash Feldspar /Soda Feldspar
- Quartz Powder (silica sand)
- Ball clay, kaolin
- Talc powder

Clay and feldspar make up the majority of ceramic materials. Contrarily, feldspar is a crucial flux in the mixture because it has the ability to accelerate the melting of quartz. The type and quantity of feldspar directly affects how low the melting point of quartz is. Ceramic tiles' structural integrity is harmed by low temperatures, but is strengthened by extremely high temperatures during hardening [19].

Depending on the manufacturer, different amounts of ceramic mixture are used. Ceramics are generally easier to shape when there is a higher concentration of clay than feldspar, which results in glassy ceramics. While potash feldspar is white, sodium feldspar has a brownish hue. The choice of raw materials affects the color of the finished product after firing. Clay and kaolin control the durability, makeup, and plasticity of ceramics [19].

2.6.3 Classification of ceramics

The volume of clay-based ceramics produced is far greater than that of non-clay ceramics, and clay continues to be the most fundamental and significant of ceramic materials, despite the expansion of the range of things that can be called "ceramic." Ceramics are available in a huge range of sizes and shapes. The first thing that likely comes to mind is tableware,

like cups, saucers, and plates. Sanitary ware, on the other hand, is only a small portion of the entire ceramic spectrum, which also includes sewer pipes, sanitary items, chemical resistant, porcelain, acid resistant ware for chemical plants, all kinds of glass, earthenware, bone china, and porcelain in addition to bricks, tiles, sanitary ware, and much more are ceramic products that are used in the day to day life.

Refractories are a vital component of ceramic product because of their ability to withstand high temperatures. Ceramics can be divided into two categories: those used at room temperature and those used at high temperatures. These categorizations can then be further divided into porous and non-porous products after firing, such a division is shown in Figure 2.4 below [18].

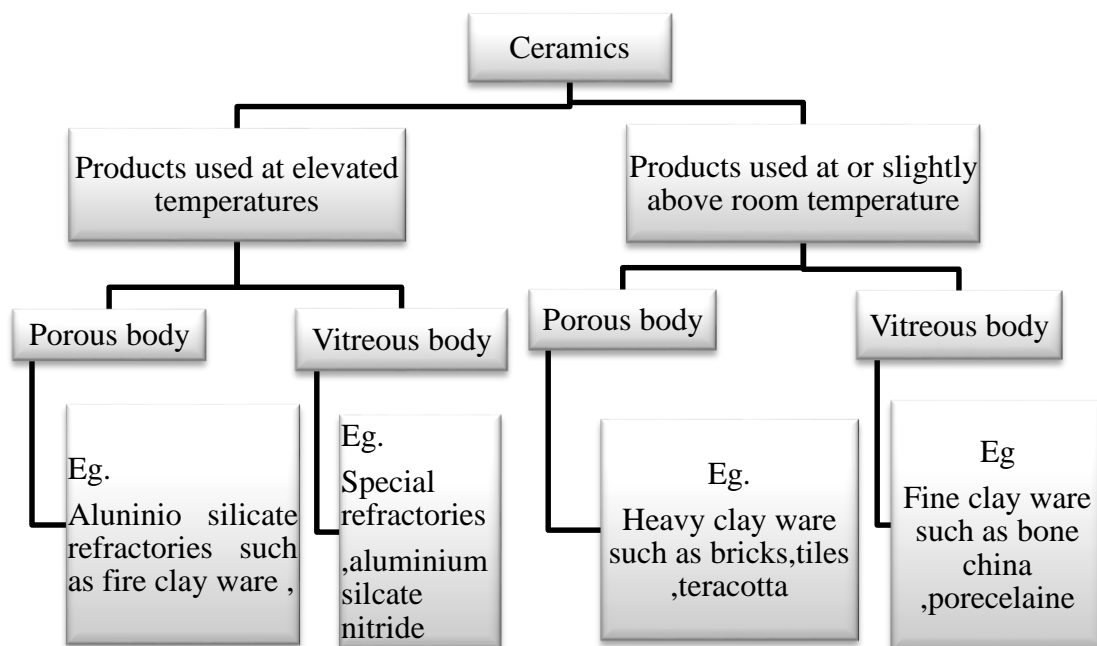


Figure 2.4 Classification of ceramic products [18].

2.7 Ceramic production in Ethiopia

The main ceramic manufacturing factories in Ethiopia are Tabor Ceramics Products Share Company in Hawassa, and in more recent years, new companies like Di Yuan Ceramics Private Limited Company in the Oromia region in Dukem Eastern Industrial Zone have begun to produce a variety of ceramic goods. Since the company produces a variety of ceramic goods, the production process at Tabor Ceramics Products Share Company is discussed below for this particular project.

Tabor Ceramic Product share Company SC

In the past, Tabor Ceramic Products Share Company was Ethiopia's sole ceramics manufacturing facility. It is located in Hawassa town, in the south nation's nationalities and peoples region. The plant began producing in 1987 G.C. with a planned annual output of 1041 tons of tableware, 938 tons of sanitary items, and 2813 tons of tiles. However, the company's production capacity has recently been increased.

The oldest ceramic factory in Ethiopia, Tabor Ceramic Product Share Company, produces a variety of ceramics. The factory is divided into three departments: one that produces tiles, another produces sanitary items, and the third produces tableware. The company is intended to produce 6,000 tons of ceramic products overall, but for a variety of reasons, including electric power outages and ineffective manufacturing equipment, the factory was unable to operate at its full capacity, as shown in Table 2.4. According to Tables 2.5 and 2.6 below, the Company manufactures those products using locally accessible raw materials with various physical and chemical properties. According to table 2.7, the total waste deposits within the factory compound, which are found to be occupying the free spaces suggested for various factory operations, are represented by the ceramic scrap generated from respective products that are found to be unsuitable for recycling [20]. These wastes have a significant negative impact on both the factory's operations and the environment.

Table 2.4 Production Capacity of Tabor ceramic Factory.

No	Plant Type	Annual Design Production Capacity (ton)	Annual Total Designed Production Capacity (ton)	Annual Production Capacity (ton)
1	Wall tile plant	3,000	6,000	65-70 % of designed capacity (3,900-4,200)
2	Sanitary ware plant	1,000		
3	Table ware and Insulation plant	2,000		

Table 2.5 Factory product ranges raw material.

	Factory product Ranges		
	Sanitary ware	Table ware	Ceramic tile
Raw Materials Used	<u>Body</u>	<u>Body</u>	<u>Body</u>
	Quartz/silica sand	Quartz	Quartz/silica sand
	Feldspar	Feldspar	Feldspar
	Kaolin	Kaolin	Kaolin
	Ball Clay	Mugar Clay	Ball Clay
	<u>Glaze</u>	<u>Glaze</u>	<u>Glaze</u>
	Quartz	Quartz	Quartz
	Feldspar	Feldspar	Feldspar
	Lime stone	Lime stone	Limestone
	Kaolin	Kaolin	Kaolin
	Frit Glaze	Frit Glaze	Frit Glaze
	Glaze Binder	Glaze Binder	Glaze Binder

Table 2.6 Mineral composition of raw materials.

% by weight	Quartz	Feldspar	Kaolin	Mugar Clay	Harar Clay	Limestone
SiO ₂	99.8	64.02	46.30	66.85	63.30	5.32
Al ₂ O ₃	0.08	18.90	38.20	19.05	19.68	0.74
Fe ₂ O ₃	0.01	0.07	0.94	5.72	3.00	0.86
TiO ₂	0.01	0.01	0.06	1.41	0.05	-
MgO	0.02	0.21	0.15	-	1.10	0.64
CaO	0.01	0.02	0.08	1.95	0.01	51.46
Na ₂ O	0.03	1.24	0.05	3.01	0.30	0.12
K ₂ O	0.01	12.80	0.37	-	3.80	0.04
MnO	-	-	0.03	-	0.01	0.04
P ₂ O ₅	-	0.22	0.04	-	0.04	0.12
BaO	-	0.01	0.01	-	-	-
Rb ₂ O	-	0.88	-	-	-	-
SrO	-	-	0.01	-	-	-
Others(L.O.I)	0.14	0.95	13.80	8.40	6.45	40.70

Table 2.7 Amount of Waste Generated at the Factory.

No	Plant Type	Designed Wastage (%/ton)	Total Average annual design wastage (%/ton)	Total Average annual actual wastage (%/ton)
1	Wall tile plant	10/300	10/600	13/780
2	Sanitary ware plant	10/100		
3	Table ware and Insulation plant	10/200		

Ceramic Production in Tabor Ceramic Share Company

Ceramic Tiles manufacturing in Tabor ceramic products S.C

This departments covers more than 60 % of the designed manufacturing capacity of the factory. The basic phases of tile production include raw material preparation, spray drying and granulation, biscuit making by pressing drying, primary firing of biscuits, secondary firing, inspection, packing, and shipping to customers as shown in Figure 2.5 below. The Plastic clay, kaolin, quartz lime stone, and feldspar are raw materials utilized in this field [21].

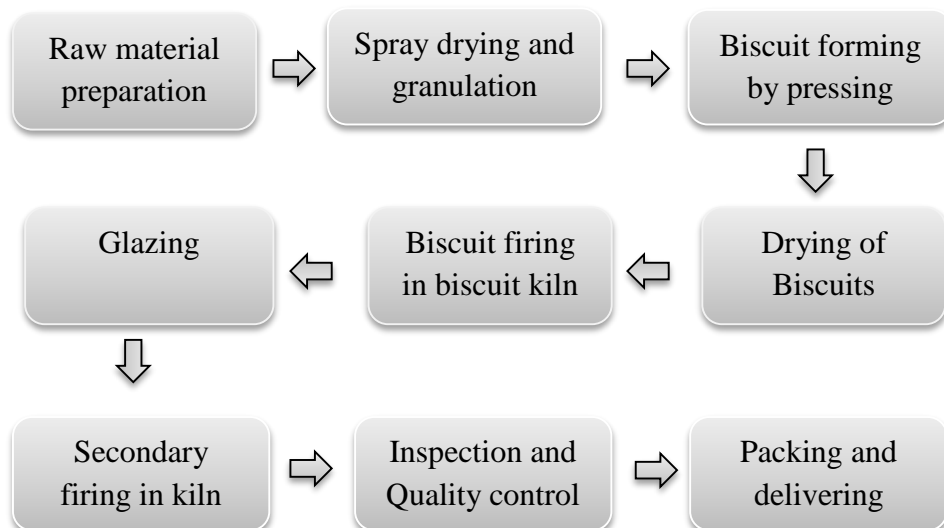


Figure 2.5 Tiles manufacturing process in Tabor ceramic products SC [21].

2.8 Ceramic wastes

Ceramic waste can be divided into two categories based on where the raw materials were mined. All fired wastes generated by structural ceramic factories that only produce items like brick, blocks, and roof tiles using red pastes fall under the first category. The second category is all stoneware ceramic-fired waste, including bathroom and kitchenware. These producers use both red and white paste, but white paste is used more frequently and in greater quantities. The fired ceramic waste is divided into each category based on the production process [15]. This classification is shown in the diagram below in Figure 2.6

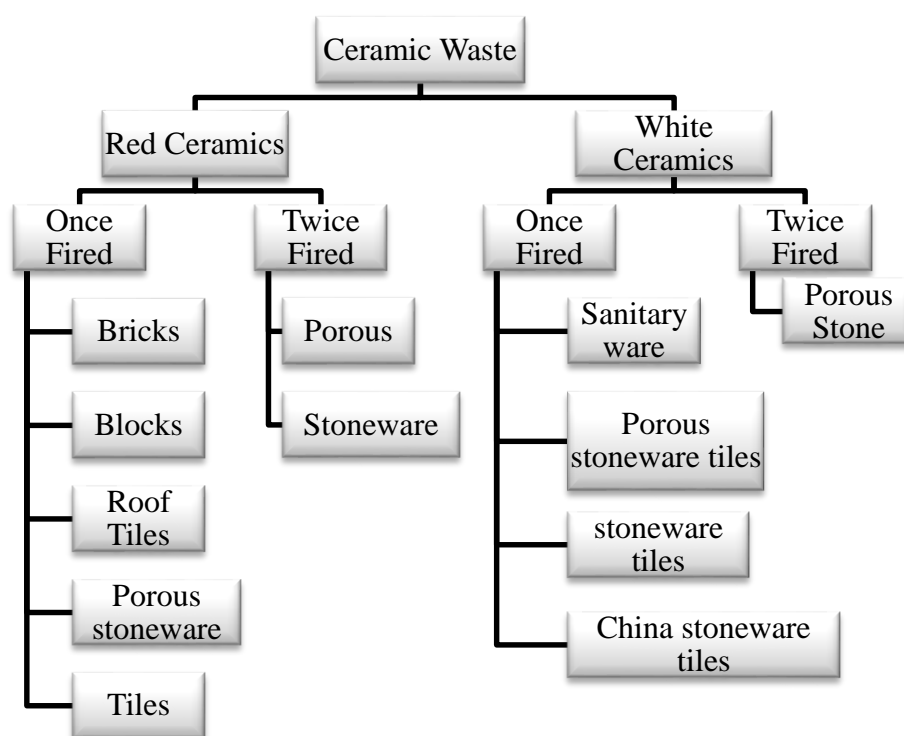


Figure 2.6 Ceramic Wastes classification based on type and production [15].

2.8.1 Recycling of waste ceramics

There are massive amounts referred to as rejects, produced when ceramic products are manufactured in factories. These wastes come from final products that may be unsafe for humans due to flaws that make them unfit for market sale, widely known imperfections in the crafts include internal fractures ,daunting (cracking of pottery caused by stress and pressure that occur after firing and cooling) ,and bloating. Even the Plaster of Paris, ceramic manufacturing fabrication molds, typically lose their effectiveness after ninety product casts, though some built to last considerably longer. Most of the time, molds that

have expired are thrown away. These cracked ceramic objects and used Plaster of Paris molds are environmental risk and cause aesthetically an unwanted detractions at open dumpsites [21].

A common waste of building construction and demolition sites is ceramic junks from wall and floor tiles, sanitary fixtures, table ware products, and electrical installation. Reprocessing or reusing of these ceramics helps reduce the reliance on natural resources by preventing large amounts of waste from going into dumpsites. Ceramic products can be recycled or used again, which can assist in lowering emissions and the use of toxic materials in glaze production. Redirecting wastes also reduces the necessity of paying increasingly expensive landfill fees. Recycled ceramics can be also employed to produce items like fine aggregate, coarse aggregates, rock bases for walkways, roads and drainage structures [15].

2.8.2 Use of ceramic waste in concrete

Ceramic wastes can be utilized as cement, fine, and coarse aggregates as ingredient in the concrete composite for both structural and non-structural concrete. Industrial wastes, like ceramics, piqued the interest of numerous researchers, because it seriously pollutes the environments when it accumulates. Tiles, sanitary products, insulators, and brick pots are just a few of the ceramic industries that produce significant amounts of industrial waste. Many characteristics of ceramics, such as the brittleness and composition, leads it to wastes [15].

According to the materials used in their production, ceramic waste can be broadly classified into two major groups as shown in figure 2.6. Group one products include bricks, structural walls and floor tiles made up of red clays ,and group two products include technical ceramics (ceramic electrical insulators),sanitary ceramics made of white clay (washbasins ,lavatory pans ,bidets, and bathtubs),and laboratory-use containers for medical and surgical supplies[15].

An overview of the literature on the various types of waste ceramics, Table 2.8 below lists the sources, type of substitution (such as fine aggregate, coarse aggregate, or both as fine aggregate and coarse aggregate and as a cement), type of concrete made, and properties of fresh and hardened concrete, such as its physical, mechanical and durability characteristics of concrete incorporating waste ceramics.

Table 2.8 Summary of previous experiments using ceramic wastes in concrete.

Reference No		[22]	[23]	[24]	[25]	[26]	
Type of waste ceramic	Electrical Insulators						
	Red ceramic (floor tiles /wall tiles)	✓			✓	✓	
	Sanitary wares						
	Bricks		✓				
	Roof tiles						
	Blocks						
	White ceramics (floor tiles /wall tiles)			✓			
	Earthen ware						
Waste ceramic replaced as	Coarse aggregate	✓	✓		✓	✓	
	Fine aggregate						
	Cement				✓		
	Both fine and coarse aggregate			✓			
Type of concrete made	Conventional concrete		✓		✓	✓	
	Ultra high/high strength concrete	✓		✓			
	Conventional Mortar						
	Self-compacted /Alkali activated concrete						
Tested properties of concrete	Fresh concrete Properties	Slump / Flow table	✓	✓		✓	
		Consistency					
		Setting time					
		Fresh density					✓
		Air content	✓	✓			
	Hardened concrete Properties (Mechanical and Durability)	Compressive strength	✓	✓	✓	✓	✓
		Splitting tensile strength	✓	✓	✓	✓	✓
		Flexural strength	✓	✓	✓	✓	
		Modulus of elasticity	✓		✓		
		Dry density			✓		✓
		Rapid chloride permeability			✓		
		Water absorption			✓		✓
		Sorpitivity			✓		
		Water Permeability	✓		✓		
		Ultra pulse velocity			✓		
		Electrical /thermal conductivity			✓		
		Acid /Sulphate resistance					
		Drying shrinkage					
		Abrasion resistance					
Volume of voids			✓				
Alkali silica /lime reactivity							
Mineral Admixture applied		✓		✓			

Table 2.8 Summary of previous experiments using ceramic wastes in concrete
(continued).

Author (Reference No)		[27]	[28]	[29]	[30]	[31]	
Type of waste ceramic	Electrical Insulators						
	Red ceramic (floor tiles /wall tiles)						
	Sanitary wares	✓	✓			✓	
	Bricks						
	Roof tiles				✓		
	Blocks						
	White ceramics (floor tiles /wall tiles)			✓			
	Earthen ware						
Waste ceramic replaced as	Coarse aggregate	✓	✓		✓	✓	
	Fine aggregate			✓			
	Cement						
	Both fine and coarse aggregate						
Type of concrete made	Conventional concrete	✓	✓	✓	✓		
	Ultra high/high strength concrete					✓	
	Conventional Mortar						
	Self-compacted /Alkali activated concrete						
Tested properties of concrete	Fresh concrete Properties	Slump cone / Flow table	✓	✓	✓		✓
		Consistency					
		Setting time					✓
		Fresh density	✓				
		Air content					
	Hardened concrete Properties	Compressive strength	✓	✓	✓	✓	✓
		Splitting tensile strength	✓	✓		✓	✓
		Flexural strength	✓		✓		
		Modulus of elasticity/rupture				✓	
		Dry density	✓				✓
		Rapid chloride permeability					
		Water absorption					✓
		Sorptivity					
		Water Permeability	✓				
		Ultra pulse velocity					
		Electrical/thermal conductivity		✓			
		Acid /Sulphate resistance					
		Drying shrinkage					
		Abrasion /frost resistance	✓	✓			✓
Volume of voids							
Alkali silica / lime reactivity							
Mineral admixture		✓			✓		

Table 2.8 Summary of previous experiments using ceramic wastes in concrete
(continued).

Author (Reference No)		[32]	[33]	[34]	[35]	[36]	
Type of waste ceramic	Electrical Insulators						
	Red ceramic (floor tiles /wall tiles)	✓				✓	
	Sanitary wares		✓				
	Bricks		✓	✓			
	Roof tiles						
	Blocks						
	White ceramics (floor tiles /wall tiles)		✓				
	Earthen ware				✓		
Waste ceramic replaced as	Coarse aggregate	✓	✓	✓		✓	
	Fine aggregate						
	Cement						
	Both fine and coarse aggregate						
Type of concrete made	Conventional concrete	✓	✓	✓	✓	✓	
	Ultra high/high strength concrete						
	Conventional Mortar						
	Self-compacted /Alkali activated concrete						
Tested properties of concrete	Fresh concrete Properties	Slump cone / Flow table		✓	✓		✓
		Consistency					
		Setting time					
		Fresh density		✓			✓
		Air content	✓		✓		
	Hardened concrete Properties	Compressive strength	✓	✓	✓	✓	✓
		Splitting tensile strength	✓		✓	✓	
		Flexural strength	✓		✓		
		Modulus of elasticity/rupture					
		Dry density					✓
		Rapid chloride permeability				✓	
		Water absorption	✓			✓	
		Sorptivity					
		Water Permeability					
		Ultra pulse velocity					
		Electrical/thermal conductivity					
		Acid /Sulphate resistance					
		Drying Shrinkage				✓	
		Abrasion resistance					
		Volume of voids					
Alkali silica / lime reactivity							
Mineral admixture					✓		

Table 2.8 Summary of previous experiments using ceramic wastes in concrete
(continued).

Author (Reference No)		[37]	[38]	[39]	[40]	[41]	
Type of waste ceramic	Electrical Insulators						
	Red ceramic (floor tiles /wall tiles)		✓			✓	
	Sanitary wares /bone china ceramics	✓	✓	✓	✓		
	Bricks			✓			
	Roof tiles						
	Blocks						
	White ceramics (floor tiles /wall tiles)						
	Earthen ware						
Waste ceramic replaced as	Coarse aggregate					✓	
	Fine aggregate	✓	✓	✓	✓		
	Cement						
	Both fine and coarse aggregate						
Type of concrete made	Conventional concrete	✓	✓	✓	✓	✓	
	Ultra high/high strength concrete	✓					
	Flow able sand concrete		✓				
	Self-compacted /Alkali activated concrete						
Tested properties of concrete	Fresh concrete Properties	Slump cone / Flow table	✓	✓	✓	✓	✓
		Consistency				✓	
		Setting time					
		Fresh density	✓	✓	✓		
		Air content	✓	✓			
	Hardened concrete Properties	Compressive strength	✓	✓	✓	✓	✓
		Splitting tensile strength			✓		✓
		Flexural strength		✓			
		Modulus of elasticity/rupture		✓	✓		
		Dry density		✓			✓
		Rapid chloride permeability					
		Water absorption		✓			
		Sorptivity					
		Water Permeability					
		Ultra pulse velocity					
		Thermal conductivity				✓	
		Acid /Sulphate resistance					
		Drying shrinkage		✓			
		Abrasion /Fire resistance		✓	✓	✓	
		Volume of voids					
Alkali silica / lime reactivity							
Mineral admixture				✓			

2.9 Characteristics of waste ceramics aggregate

Various researchers from all over the world tested the physical and mechanical characteristics of concrete that contained ceramic wastes in the form of fine and coarse aggregate at various substitution levels. It is obvious that the component ceramic aggregates, regardless of whether used as fine or coarse aggregate, determines all of the concrete's properties [22].

2.9.1 Specific gravity of waste ceramic aggregates

The weight of a substance is compared to the weight of equivalent volume of water to compute its specific gravity. According to this description, the material is wholly solid. Although aggregate pores can be permeable or impermeable, their structure (size, number, and continuity pattern) affects the aggregates' permeability, specific gravity, and ability to absorb water [42]. Typically, when the term "specific gravity" is used to describe aggregates, it tends to refer to the density of individual particles rather than the aggregate mass as a whole [7].

The range of coarse ceramic aggregate's specific gravities is 1.87 to 2.64 [24,25,26,27,30,31,32,33,34,35,36,41,43,44,45,46,53] and that of fine ceramic aggregate is 2.26 to 2.97 [29,37,38,39,40,43,44,45,47].

Alves A. [39] managed to show that ceramic waste from sanitary ware had the maximum specific gravity value, 2.97, for fine aggregate. Additionally, Zegardlo et al. [31] used ceramic waste from sanitary ware while still displaying the highest value of 2.64 for coarse ceramic aggregate. According to Bikash et al. [26], the lowest specific gravity value for coarse ceramic aggregates was 1.87, and P.O.Awoera et al. [49] reported a value of 2.26 for fine ceramic aggregate. Ceramics have a lower specific gravity than natural aggregates. Although there are satisfactory materials for which the specific gravity falls outside of this range, the specific gravity of commonly used aggregates typically falls between 2.6 and 2.7 [7].

2.9.2 Size, thickness, shape, texture and color of waste ceramics aggregates

To reduce ceramic waste from different sources into smaller pieces, hammering is frequently used. Waste structural or stoneware ceramics are obtained from building sites

or directly from the disposal area of ceramic manufacturing facilities. These smaller pieces are crushed to produce the required aggregate size for the intended work, either using a laboratory jaw crusher or a hammer [22, 25, 50].

A maximum size of 10 mm was advised for ceramic tile aggregates because ceramic tile thicknesses are frequently in the 3–10 mm range [22, 27]. The majority of researchers favored a maximum ceramic aggregate size of 12.5mm [44,46,48,50], regardless of the source of the ceramic waste. On the other hand, a number of researchers have claimed to use a maximum ceramic aggregate size of 20 mm [23, 25, 30, 43, 51] and a size of 25 mm [26].

When choosing the right aggregate size, the ceramic's thickness must be taken into account [25]. The largest sieve that at least ninety percent of the aggregate can pass through is typically used to calculate an aggregate's maximum size based on its sieve analysis [7].

Numerous sources produce irregular, angular, flat, and flaky ceramic aggregates [22,25,26,27,30,31,32,33,34,35,36,41,43,44,45,46]. However, floor and wall tiles are the ones that frequently create flaky, flat, and elongated shaped aggregates [51,53]. Sharpe edges are usually visible in the crushed ceramic aggregates [46].

Depending on the type of ceramic, reddish or white colored ceramic aggregates are typically used. The reddish color of ceramic wastes has reportedly been attributed to the presence of a substantial portion of iron oxide (Fe_2O_3) [54].

Likewise, the surface of ceramic aggregates can be either smooth or rough [43,46,49,51]. A glazed smooth surface is typically present on the side of sanitary ware and tile aggregates [22,25,26,27,30,31,32,33,34,35,36,41,43,45,46]. The ceramic aggregate's smooth surface do not offer cement paste good adhesion [26].

On the other hand, P.O. Awera et al. [49] indicated that the crushing of ceramic wastes resulted in a much rougher surface ceramic tile and sanitary ware aggregates compared to that of natural aggregate.

2.9.3 Bulk Density of waste ceramics

Researchers reported that the bulk densities of fine and coarse ceramic aggregate ranged from 1010 to 2969 kg /m³ and 966 to 2401 kg/m³, respectively [22 -59]. Most searchers

discovered that ceramic fine and coarse aggregates had lower bulk densities than equivalent natural fine and coarse aggregates. It has been discovered that ceramic aggregates made from sanitary ware ceramic have higher bulk density value (greater than 2000 kg/m³).

2.9.4 Moisture content and water absorption

If the aggregates have surface moisture, they add additional water to the mix, increasing the water to cement ratio. On the other hand, if the aggregates are dry, they absorb water from the mixing water and change the workability. These two circumstances are bad for concrete's quality. As a result, it is essential to comprehend the state in which the aggregate is used when calculating or measuring the quantities of concrete [7].

The results of multiple studies indicate that ceramic aggregates can absorb more water than natural aggregates [22-59]. For fine aggregate and coarse ceramic aggregates, the highest water absorption values are 14.37 % [24] and 17.82% [35], respectively. The higher the porosity of ceramic aggregates the higher it contributes to their strong water absorption capacity. Aggregate water absorption has an impact on the consistency and workability of concrete. Therefore, in order to minimize the negative effects, it is essential to understand the moisture content and water absorption of ceramic aggregates [7].

2.9.5 Porosity of waste ceramics

The qualities of the final concrete are affected by the bulk specific gravity, permeability, and water absorption of the aggregates, all of which are impacted by its porosity. Surface pores are thought to be impervious to cement paste unless their apertures are very large due to cement paste's viscosity [7].

According to Guendouz [38], the porosity of the sanitary ceramic wastes used has a porosity of fifty percent, which is higher than the porosity of the natural aggregates. Due to their high porosity, ceramic aggregates can absorb water into their pores, causing internal curing, and improving cement hydration in concrete [55]. Long-span structures can be constructed as the apparent density of recycled ceramic concrete and as a result, the self-weight of the building, decreases as the porosity of ceramic aggregate increases [52].

2.10 Physical characteristics of ceramic aggregate concrete

2.10.1 Workability

Freshly mixed concrete needs to be workable because it affects how easily it can be mixed, transported, placed, and finished without segregating. The slump test is typically used to evaluate the consistency or workability of concrete. In the majority of tests, using ceramic waste as an aggregate reduced the slump value of the finished concrete, because of the high porosity and water absorption, angular shape, and rough surface of the ceramic aggregate [22,49].

In concrete mixes containing zero to hundred percent fine ceramic aggregate content and zero to seventy five percent ceramic tile coarse aggregate content, Awoera et al. [49] achieved medium to high workability. However, they did note very little workability in concrete with slump height of 40 mm and hundred percent ceramic coarse aggregate. In addition, Tavakoli et al. [56] found that adding ceramic tile aggregate as a replacement for coarse aggregate with a partial replacement of zero to forty percent and sand with a substitution of zero to hundred percent resulted in a modest decrease in slump values. This behavior was brought on by the aggregate's glazed surface, which may result in inadequate adhesion with other components in the mix [49].

Daniel and Ahmad [53] also attributed the decrease of slump value to the fact that ceramic tile aggregate are more angular and absorb more water than natural aggregates. As the proportion of coarse ceramic tile particles in the concrete increased, they also observed a decline in slump value. However, the researchers observed an increase in slump value with rising water to cement ratio at all replacements.

In conclusion, when using ceramic wastes as natural aggregate replacement in concrete, slump height generally decreases as ceramic aggregate quantity rises from 50% to 100% substitution, with a few notable exceptions [22, 49, 53, 56].

2.10.2 Compression strength

In-depth research into compressive strength, the most important fundamental characteristics of structural and non-structural concrete, has been done using ceramic waste aggregate. Researchers experimented at various ceramic coarse and fine aggregate

percentages, various curing times, temperatures, and different test conditions to produce different classes of concrete strength [22- 49].

In accordance with Medina et al.[57] ,as the amount of coarse ceramic sanitary ware aggregate in the concrete mixes increased ,so did the concrete's compressive strength. The average 28 day compression strength of concrete with zero, fifteen, twenty and twenty-five percent coarse sanitary ware aggregate content was 35.87 MPa, 37.24 MPa, 38.53 MPa, and 39.83 MPa, respectively. According to the author, the coarse sanitary ware aggregate's irregular shape provides superior specific surface area when compared to natural aggregates ,resulting in a strong bond between the ceramic aggregate and cement paste and enhanced mechanical strength in ceramic aggregate concrete.

In place of natural coarse aggregates, Anderson et al [51] evaluated the mechanical strength of concrete using aggregate from floor tile, wall tile, and waste tiles. When compared to the reference concrete, they discovered that CA concrete has greater compressive strength up to a twenty percent substitution ratio for floor tile and up to fifty percent ratio for wall and waste tile aggregates. However they found that, when compared to the control concrete samples, the compression strength of the floor tile, wall tile, and waste tile aggregate concrete decreased by 4.3%, 5.6% and 28.3% respectively, with a 100% substitution ratio. They claim that the surface texture of the tile aggregates was to blame for the significantly weaker aggregate – paste binding in the Interfacial Transition Zone (ITZ) of the tile aggregate concrete compared to the control samples, which resulted in the strength loss.

The characteristics of concrete made with floor and wall tile aggregates as a complete substitution for natural fine and coarse aggregates were experimented by Hakan Elci [50].The 28 day compression strength of the floor tile concrete was higher than that of the wall tile concrete when compared to concrete with limestone aggregate. The author claims that the relative higher density and lower water absorption of floor tile aggregates were what led to the difference in mechanical performance between concrete with floor and wall tile aggregates.

According to the reviewed experimental studies, the following are the factors that cause a rise in compression strength:-

- Ceramic aggregate has a high specific surface area for a solid bonding with cement paste due to its irregular shape and rough surface.
- Because ceramic aggregate has a high porosity level, which promotes internal curing and ensures cement hydration.
- The pozzolanic properties and hardness of ceramic aggregates.
- Ceramic particles have a higher water absorption rate, which increases the potential for additional hydration.
- Ceramics aggregates have a uniform homogeneous structure.

However, the following causes can be used to explain why ceramic aggregate concrete's compression strength has decreased:-

- Because ceramic aggregates are so brittle and flaky.
- Poor aggregate-paste bonding results from the flat, smooth surface texture of ceramic aggregates.
- Ceramic aggregates have lower bulk density than natural aggregate.

2.10.3 Splitting tensile strength

The splitting tensile strength of concrete is a method for inferring the progressive cracking pattern of concrete under tensile load as well as the amount of force that causes a crack to form in it [5].

The splitting tensile strength of concrete using 15% -25% coarse sanitary ware aggregates increased by 15% -25% in comparison to control mixes. It was claimed that the specific surface area of ceramic aggregate's and irregular shape leads to a stronger aggregate-paste bond, which increases the high strength of CA concrete [57]. However, Garca-gonzalez et al. [46], found that the splitting tensile strength of 100% coarse sanitary ware aggregate concrete was almost identical to the reference sample concrete.

According to Hunchate et al. [47], adding coarser ceramic insulator aggregate to concrete decreased the splitting tensile strength throughout the entire curing process. The 28 day splitting tensile strength of ceramic aggregate concrete decreased by 30% in comparison to the control concrete when 100% replacement was used. They claimed that the increased

water absorption of ceramic aggregates caused poor aggregate-paste bonding, which in turn decreased the final concrete's splitting tensile strength.

Ceramic insulator aggregate concrete had a lower splitting tensile strength than the reference concrete, according to Senthamarai and Manoharan [43]. The splitting tensile strength of ceramic aggregate and natural aggregate concrete ranged from 4.5 to 3.2 MPa and 5.5 to 3.9 Mpa, respectively, when the w/c ratio changed from 0.35 to 0.6. Additionally, they found that the tensile to compressive strength ratio of ceramic aggregate concrete was lower than that of control concrete.

2.10.4 Flexural Strength

A concrete's capacity to withstand deformation when subjected to flexural load is measured as flexural strength. The highest stress that is applied to the concrete at the time of failure is represented by it [5].

The majority of the researchers found that CA concrete had lower flexural strength than conventional concrete except in few cases.

When the amount ceramic tile waste substituted for natural aggregates increases, Anderson et al.[51] found that the flexural strength of the concrete decreased. In comparison to concrete made with natural aggregate, they found that concrete made of entirely coarse floor and wall tile had strength loss of 17.9%. The flexural strength loss for waste tile aggregates, however, was estimated to be 25% when using a 100% replacement ratio. Daniyal and Ahmad [53], on the other hand, found that using ceramic tile as the coarse aggregate increased the flexural strength of concrete by 32.2% when compared to the reference concrete. The flexural strength of tile aggregate concrete was higher than the control concrete (5.2 Mpa), ranging from (5.66 to 6.95 MPa) [58].

According to Tabak et al. [59], ceramic aggregate concrete had less flexural strength than the control concrete when the natural coarse and fine aggregate were entirely replaced by floor tile aggregates. The highest results were obtained when 30% ceramic tile was used as the coarse aggregate, which increased the flexural strength of CA concrete by 33.7% in comparison to control concrete [58]. However, the flexural strength of CA concrete was lower than the reference concrete when the fine and coarse tile aggregate are 100% replaced with natural aggregates [50,59].

2.11 Literature Summary

This chapter has provided a detailed review of recent information on the physical and mechanical characteristics of concrete that contains ceramic waste as an aggregate. It includes various experimental studies that have been conducted around the world, along with their properties and findings. The literature's information and findings indicate that finding new eco-materials is necessary in order to minimize the environmental impact of synthetic materials. Additionally, it gives a glimpse into the ongoing studies and applications pertaining to the creation of green concrete using waste ceramic. The use of ceramic wastes in commercial projects are not common due to the wide variation in mechanical characteristics discovered from various experimental studies. Since its inception, researchers have examined the characteristics of ceramic aggregate based concrete by adjusting the substitution levels, mix proportions, and other elements. Earlier research has generally attempted to demonstrate that crushed and sieved waste tiles can be used to replace both coarse and fine aggregate. Using the literature reviews as a foundation, the following conclusions are reached :-

- i. Depending on their source, ceramic aggregates can have a smooth surface texture, porous, uneven, angular, flat, or flaky in shape, and are frequently reddish or white in color.
- ii. Ceramic aggregate's specific gravities range from 2.26 to 2.97 for fine aggregates and from 1.87 to 2.64 for coarse aggregates, respectively. The bulk densities for fine and coarse ceramic aggregates are typically (1010 -2969) kg/m³ and (966 - 2401) kg/m³ respectively.
- iii. Ceramic aggregates are remarkably water absorbing because they have a higher porosity than the natural aggregates. Depending on the source, ceramic aggregate water absorption varies greatly.
- iv. Due to the high porosity, high water absorption, angular size, and rough surface of ceramic aggregates, ceramic aggregate concrete is frequently claimed to have low slump values for almost all types of ceramic aggregates.
- v. Due to the lower bulk density, using ceramic wastes as aggregate reduces the fresh and dry density of the finished concrete regardless of the type, source, or substitution ratios used.

- vi. Based on the reviewed literatures, adding coarse tile and sanitary ware to concrete increases its compression strength. The irregular shape and rough surface of these ceramic aggregates provide a high specific surface area of strong bonding with cement paste. The standard compressive strength for structural concrete specified by the ACI code is typically met by CA aggregate.
- vii. Coarse tile and sanitary aggregates both outperformed other substitute ceramic wastes in terms of the splitting tensile strength of CA concrete.
- viii. The flexural strength of ceramic aggregates concrete increased by the addition of coarse tile, sanitary wares, and insulator aggregates, except in few exceptions.

Even though there have been a few recent reported works using other waste materials like glass and bricks, very little works have been done on the use of waste materials in concrete in Ethiopia. In light of this, the purpose of this study is to ascertain the advantages of ceramic waste when it is used as coarse aggregate in concrete. In this experimental study, the workability, compressive strength, split tensile strength, and flexural strength of concrete with various percentages of waste ceramics as coarse aggregate are taken into consideration.

2.12 Research Gap Statement

The usage of crushed and sieved ceramic waste tile replacement for coarse aggregate in concrete production is not common in Ethiopia. As a result, there is a gap in the use of this material for concrete work that makes a contribution. Almost all waste ceramic tiles are not recycled for useful purposes rather it's being disposed as a waste. Additionally, it is not common practice in the construction sector to use ceramic waste in concrete projects. It is the author's believe that, it might be due to lack of awareness and experimental research regarding the use of ceramic waste as a component of concrete. Waste ceramic tiles are dumped as waste and in some places it is used as a ceramic chips for decorating floor and walls. Therefore, the study's goal is to produce concrete using this inexpensive but valuable material as one of its main ingredients in specified percentage.

CHAPTER 3 METHODOLOGY AND PROPERTIES OF MATERIALS

3.1 Introduction

Concrete mixture with partial replacement of coarse aggregate with crushed waste ceramic was prepared. A maximum aggregate size of 19mm was used. The materials used for the test are natural coarse aggregate with maximum size of 19mm, crushed ceramic waste with maximum size of 19mm, fine aggregate (sand), cement (Dangote OPC) and water.

All laboratory examinations on the ingredients used for concrete making were done in Addis Ababa Institution of Technology Construction Material Laboratory; whereas the chemical composition of ceramic waste was carried out at Geological Survey of Ethiopia, Geosciences Laboratory.

3.2 Methodology

The methodology devised to carry out the experiments was prearranged and executed by using laboratory test for the concrete making ingredients and the concrete itself. In order to have better understanding of the study area different literature review has been carried out about properties of fresh and hardened concrete, concrete making materials, waste ceramic aggregate and ceramic containing concrete.

3.3 Steps followed to carry out the experiment

The steps followed to conduct the experiments are as shown below :-

1. Ceramic waste was collected from building sites in Addis Ababa.
2. The collected ceramic wastes were crushed with hammer (ball-peen) by hand, due to inavailability of ceramic crushing machine during the time of the experiment, to maximum size of 19mm and sieved accordingly.
3. Both coarse and fine aggregate were bought from the local market in Addis ababa and were washed and sieved properly.
4. Cement (Dangote OPC 42.5N) was purchased from the local market .

5. Laboratory tests were conducted at AAiT Material Testing Laboratory for:
 - Fine aggregate (sand) :particle size distribution,unit weight,specific gravity(bulk ,apparent and SSD) ,water absorption,moisture content ,silt content and finess modulus.
 - Coarse aggregate : particle size distribution,unit weight,specific gravity(bulk ,apparent and SSD) ,water absorption and moisture content.
 - Crushed waste ceramic : sieve analysis,unit weight,specific gravity(bulk ,apparent and SSD) ,water absorption and moisture content.
6. The cement, fine aggregate (sand), coarse aggregate, crushed ceramic waste and water were mechanically using pan type mixer and batch-ordered according to their proportions. The coarse aggregate was replaced partially with crushed ceramic waste 10%, 20%, and 30% by weight .In addition to this the control mix without ceramic waste aggregate was prepared. The mix design was done using ACI mix design manual for C20 and C25 grades of concrete.
7. Workability tests was taken for all freshly mixed concrete.
8. Concrete cube samples of size 150mmx150mmx150mm were taken from each mix and compression strength tests for 7th, 14th, and 28th day were conducted (72 samples ,each samples has a dimension of 15cm x 15cm x 15cm).
9. Splitting tensile strength test was conducted at 28th day for each concrete mix using cylindrical samples (24 samples having 15cm diameter and 30cm height).
10. Flexural strength test was conducted at 28th day for each concrete mix using beam samples (24 samples, each samples has a dimension of 10cm x 10cm x 50cm).
11. All the tests conducted (for 10%, 20%, and 30% replacement) above were analyzed by comparing them with the control mix.
12. Finally conclusions and recommendations are forwarded.

The ceramic waste materials used in this study were unused ceramic floor tiles, sourced from construction sites in Addis Ababa. All the tiles used are manufactured from Tabor Ceramics products Share Company. They were bought from the local store. In order to

provide a ceramic material that have consistent physical properties the ceramic tiles used have no attached adhesives on its surfaces.

The collected ceramic tiles were first broken manually using a ball-peen hammer into a variety of sizes using standard sieves so that to keep the uniformity with an effort given to produce ceramic pieces within 4.75-12.5mm coarse aggregate range. Using this method, each tiles were broken with an average of approximately 150 strikes using the hammer to achieve an aggregate of tile within the desired range. The crushed ceramic aggregate are more angular and less cubical or spherical than the natural aggregate.

The angularity of the ceramic tiles cannot be controlled to attain similar angularity to that of the natural coarse aggregate, as the tiles used in this study had a maximum thickness of 6mm. The only way to reduce the angularity of the ceramic tiles is to use thicker ceramic source, however Tabor ceramics Factory Share Company tiles are rarely thicker than 6mm. Therefore it is needed to reduce the nominal size of the ceramic to 12.5mm.

Upon completion of crushing procedure the ceramic wastes, the broken tiles were stored into different size ranges to be weighed and added separately in proportion matching the grading curve of the natural coarse aggregate that was partially being replaced .All ceramic materials retained on 19mm sieve are removed and crushed again, and all ceramic aggregate passing 4.75 are totally rejected. Figure 3.1 below shows ceramic wastes collected from construction sites and crushed using peen-hammer.



Figure 3.1 Crushed ceramic waste tiles collected from construction sites.

3.4 Properties of concrete making materials used for the experiment

3.4.1 Cement

The cement used for the research is Dangote OPC 42.5N.

3.4.2 Fine aggregate

The sand was bought from the neighborhood local market. In order to remove the silt and debris it was thoroughly washed with clean water. The physical tests conducted in the laboratory were sieve analysis, unit weight, specific gravity (bulk, apparent and SSD), water absorption, moisture content, silt content, and fineness modulus. All fine aggregates retained on 9.5mm sieve size were rejected.

a) Silt content

Since the sand used was river sand, it does not offer clean sand. They frequently hold other materials such as dust, loam and clay that are finer than sand. The existence of such things in the sand makes the bond between cement and aggregate less strong. The finer particles do not only reduce the strength but also the quality of the concrete made causing fast weakening. Therefore, it is essential that we make a test on the silt content and checks against allowable limits [42]. From the test result gotten, the silt amount of the sand used for this specific experiment before washing was 7.05 %, which is above the maximum requirement of Ethiopian standard. For this reason, the sand was cleansed exhaustively up until it was 2.04 %, which is acceptable [Appendix - A1.1].

b) Sieve Analysis

Sieve analysis is a procedure for the determination of the particle size distribution of the aggregate using a series of square or round openings. It is used to determine the grading of aggregate and the fineness modulus, an index to the fineness and coarseness and uniformity of aggregates [42]. The grading requirements for the fine aggregates according to ES C.D3.201 is shown below in Table 3.1 and the particle size distribution is shown in the Table 3.1 below [Appendix -A1.1].

Table 3.1 Grading Requirement for Fine Aggregate.

Percentage passing through test sieves having square openings							
Sieve size	9.5mm	4.75 mm	2.36 mm	1.18 mm	600µm	300µm	150 µm
%	100	95-100	80-100	50-85	25-60	10-30	2-10

Table 3.2 Sieve analysis fine aggregate.

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve & Retained (gm)	Wt. of Retained (gm)	Percentage retained (%)	Cumul. Coarser (%)	Cumul. Passing (%)
9.5			0	0		100
4.75	431.3	439.6	8.3	1.66	1.66	98.3
2.36	387.2	439.0	51.8	10.36	12.02	88.0
1.18	373.0	485.1	112.1	22.42	34.44	65.6
600µm	324.8	457.7	132.9	26.58	61.02	39
300µm	302.8	428.7	125.9	25.18	86.20	13.8
150µm	283.1	310.0	26.9	5.38	91.51	8.4
pan	240.4	282.50	42.1	8.42	100.0	
Total			500		280.0	

$$\text{Fineness Modulus (FM)} = \frac{\sum \text{Cumulative Coarser}}{100} = \frac{280}{100} = 2.8$$

Depending on the size of the sand, when the fineness modulus of the sand is within the range of 2.6-2.9 the sand is classified as coarse sand. From the above computation, the sand has a fineness modulus of 2.80, which is coarse sand.

The sieve analysis of the sand is depicted in the figure 3.2 below, which shows that the sand satisfy, and is within the region of specified limits.

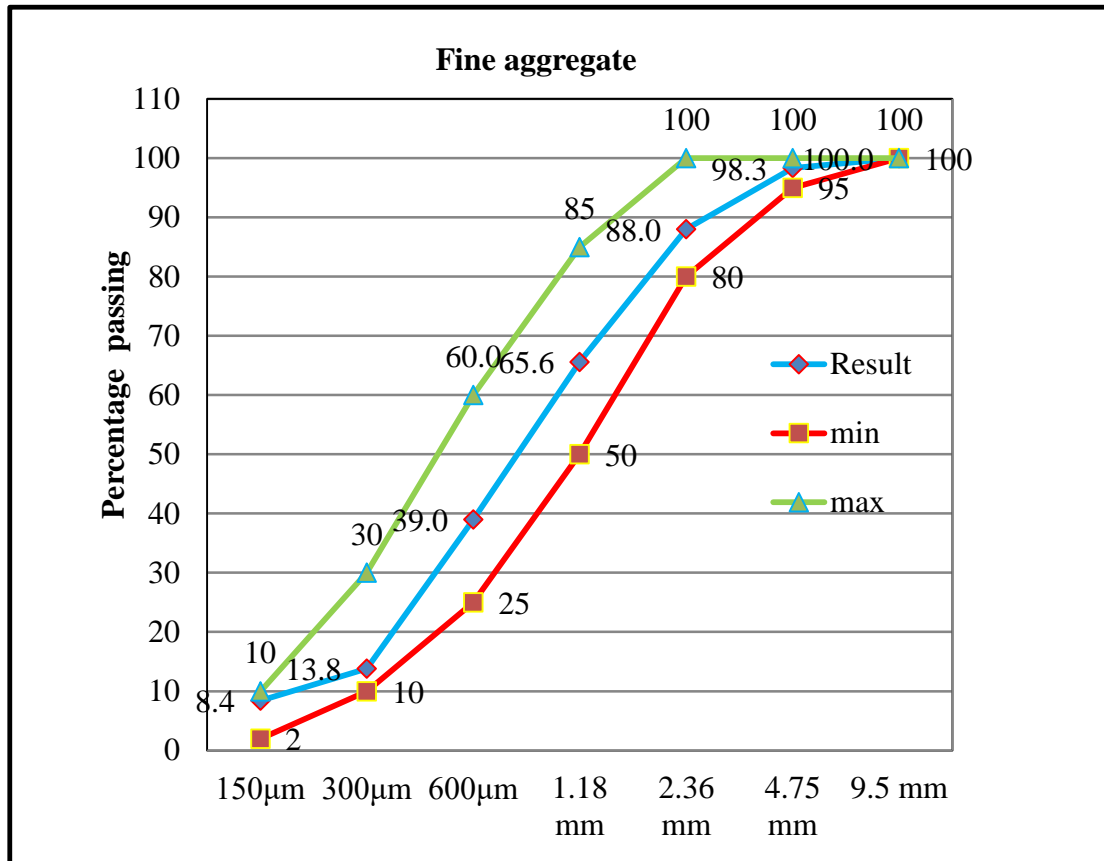


Figure 3.2 Particle size distribution curve of fine aggregate

c) Specific gravity and absorption capacity

Sand aggregates have pores that are both permeable and impermeable, hence it needs to be considered when computing the specific gravity. There are three types of specific gravity: bulk specific gravity, bulk specific gravity (SSD basis) and apparent specific gravity. When the aggregate is treated as solid material and pores are excluded it is called apparent specific gravity, whereas when the pores are considered and referring to the total volume it is called bulk specific gravity [42]. The following results were computed in the laboratory as follow [Appendix-A1.1]:

Bulk specific gravity =2.28

Bulk specific gravity (SSD Basis) =2.40

Apparent Bulk specific gravity =2.60

Absorption capacity =2%

d) Moisture content

The workability and strength of concrete is highly affected by the water to cement ratio. The water to cement ratio is specified based on the assumption that aggregates are inert (neither absorb nor give water to the mixture). But this not the case because aggregates sourced from different quarries don not comply with this i.e. ,wet aggregate give water to the mix and drier aggregates (those with below saturation level moisture content) take water from the mix affecting both workability and strength [42].

The moisture content of fine aggregate sand is computed by drying 500grams of sample sand in the oven for 14 hours with temperature of 110°C and letting it cool for one hour. Then, subtracting the oven dry weight from the sample weight dividing the result with oven dry weight and multiplying it by hundred gives the moisture content of the sand. The sand used for the project has a moisture content of 8 % [Appendix - A1.1].

e) Unit weight (bulk density)

Unit weight of the aggregate is defined as the weight of a given volume of graded aggregate. It is thus a density measurement and is also known as bulk density. The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the void between them. The unit weight is simply measured by filing a container of known volume and weighing it. The sand used is in the oven- dry state and was compacted according to the standard [42]The unit weight of the sand used for this project is 1490 kg/m³ [Appendix - A1.1].Table 3.3 below shows the summarized laboratory test results of fine aggregate.

Table 3.3 Outlined test results of fine aggregate .

No	Types of Tests		Test Result
1	Silt Content	Before washed	7.05%
		After washed	2.04%
2	Fineness Modulus		2.80
3	Moisture content		8 %
4	Unit Weight		1490 kg/m ³
5	Absorption capacity		5.48 %
6	Specific Gravity	Bulk specifig gravity	2.28
		Bulk specifig gravity(SSD)	2.40
		Apparent specifig gravity	2.60

3.4.3 Coarse aggregate

The coarse aggregate used for the study was basaltic crushed rock purchased from one of crusher plant from Goro area. Since the coarse aggregate was full of dust, it was cleansed with tap water thoroughly and was dried in an open air at the back yard of the laboratory. The nominal maximum size of 12.5mm diameter aggregate was used throughout the study. The types of laboratory tests conducted were sieve analysis (gradation), unit weight, and specific gravity (bulk, apparent and SSD), moisture content and water absorption [Appendix–A2.2]. The grading requirements for the coarse aggregates according to ASTM is shown below in Table 3.4 and the particle size distribution is shown in the Table 3.5 and in Figure 3.3 below.

Table 3.4 Grading Requirement for coarse aggregate.

Nominal size of aggregate ,mm	Percentage passing through test sieves having square openings						
	75mm	63mm	37.5mm	19mm	13.2mm	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 3.5 Sieve analysis of coarse aggregate.

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve & Retained (gm)	Wt. of Retained (gm)	Percentage retained (%)	Cumul. Coarser (%)	Cumul. Passing (%)	Standard Limit (%)
19			0	0	0	100	100
12.5	1158	1258	100	5	5	95	90-100
9.5	1163	1962	799.99	40	45	55	40-85
4.75	1260	2359.99	1099.99	55	100	0	0-10
		Total	1999.98				

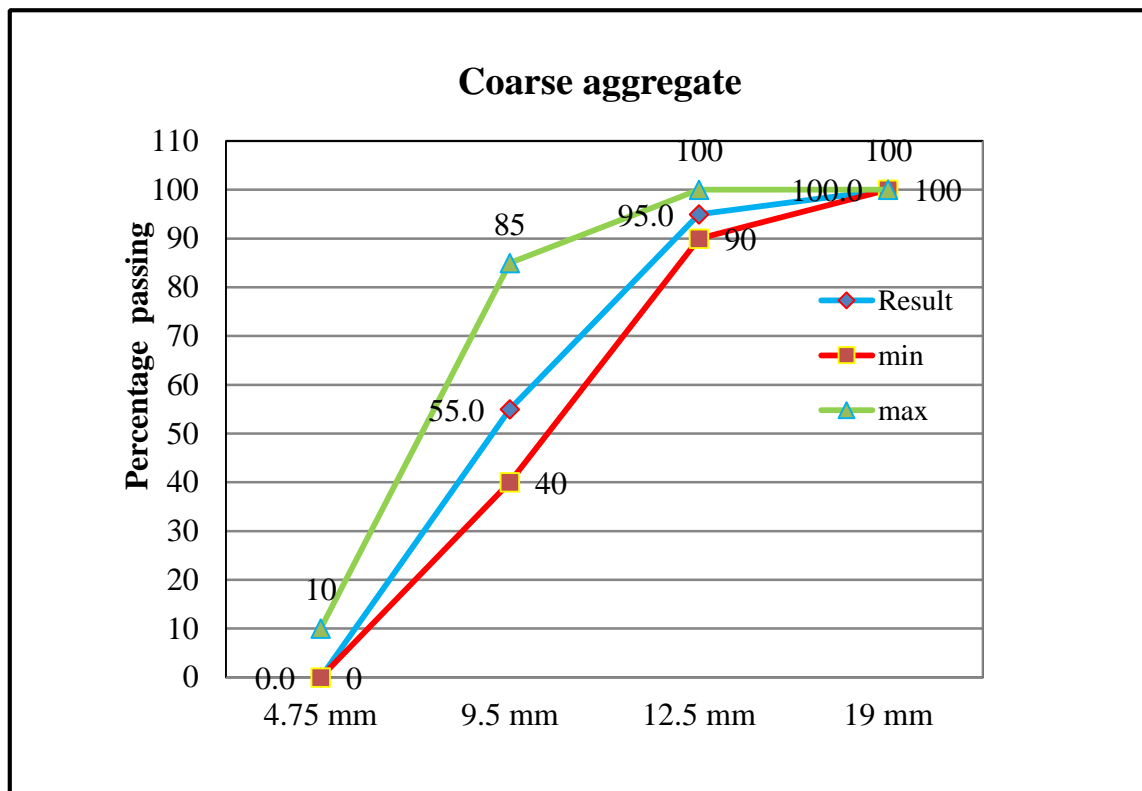


Figure 3.3 Particle size distribution curve of coarse aggregate.

In the same way as fine aggregate, the laboratory tests carried out to compute the physical properties of coarse aggregate is summarized as shown in Table 3.6.

Table 3.6 Outlined test results of natural coarse aggregate.

No	Types of Tests	Test Result	
1	Nominal maximum size	12.5mm	
2	Moisture content	4.4 %	
3	Unit Weight	1662 kg/m ³	
4	Absorption capacity	0.91%	
5	Specific Gravity	Bulk specifig gravity	2.66
		Bulk specifig gravity(SSD)	2.68
		Apparent specifig gravity	2.72

3.4.4 Ceramic coarse aggregate

a) Physical properties of coarse ceramic aggregate

The ceramic waste tile used for the study was collected from construction site in Addis Ababa around Mekannisa. The collected ceramic wastes were crushed using ball-peen hammer and sieved accordingly as that of natural coarse aggregate. The nominal maximum aggregate size of ceramic waste was 12.5mm. The crushed and sieved ceramic coarse aggregate is shown in Figure 3.4 below.

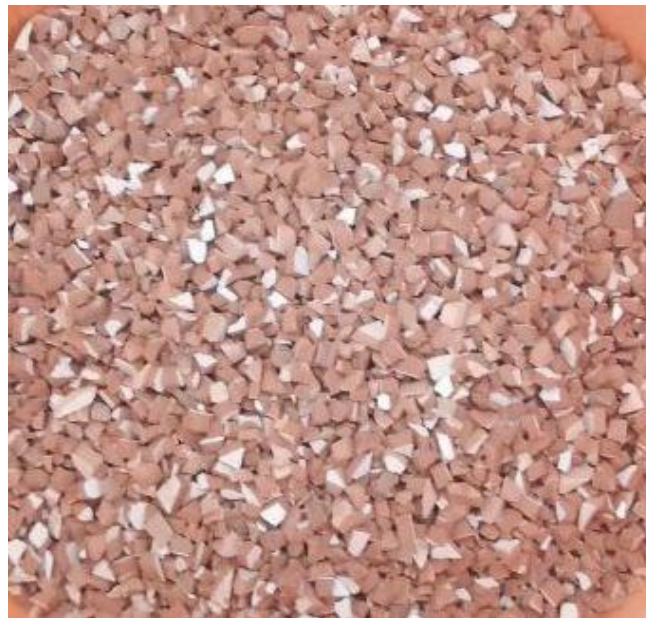


Figure 3.4 coarse ceramic aggregate.

The types of laboratory tests conducted were the same as that on natural coarse aggregate: sieve analysis (gradation), unit weight, specific gravity (bulk, apparent and SSD), moisture content, and water absorption.

The physical property tests conducted for the crushed ceramic coarse aggregate are summarized in the Table 3.7 below [Appendix – A3.3]. The tests result shows that ceramic aggregate has unit weight and specific gravity less than the natural coarse aggregate, which shows that the crushed ceramic aggregate is less dense than the natural coarse aggregate. In addition; the ceramic aggregate has higher absorption capacity than natural coarse aggregate, indicating that the ceramic is porous.

Table 3.7 Outlined test results of ceramic coarse aggregate.

No	Types of Tests	Test Result	
1	Nominal maximum size	12.5mm	
2	Moisture content	0.32 %	
3	Unit Weight	1214 kg/m ³	
4	Absorption capacity	4.50 %	
5	Specific Gravity	Bulk specifig gravity	2.32
		Bulk specifig gravity(SSD)	2.35
		Apparent specifig gravity	2.39

Sieve analysis test result of ceramic coarse aggregate is shown below in Table3.8 below. The result shows that the cumulative percent passing on each sieve complies with ASTM standard. In addition, Figure 3.5 shows the graphical representation of the gradation test result of ceramic coarse aggregate.

Table 3.8 Sieve analysis of ceramic coarse aggregate.

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve & Retained (gm)	Wt. of Retained (gm)	Percentage retained (%)	Cumul. Coarser (%)	Cumul. Passing (%)	Standard Limit (%)
19			0	0	0	100	100
12.5	1158	1258	100	5	5	95	90-100
9.5	1163	1962	799.99	40	45	55	40-85
4.75	1260	2359.99	1099.99	55	100	0	0-10
		Total	1999.98				

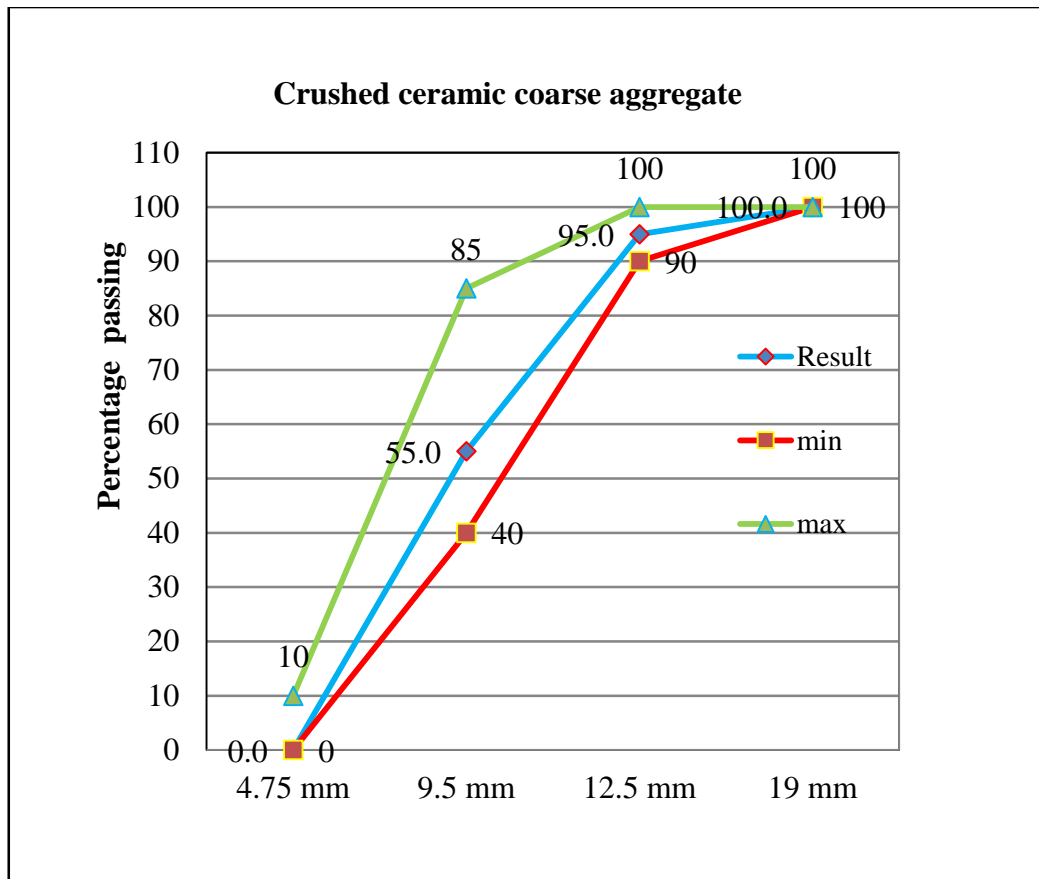


Figure 3.5 Particle size distribution curve of coarse ceramic aggregate.

b) Chemical properties of coarse ceramic aggregate

The chemical analysis of the crushed coarse ceramic aggregate samples were carried out in order to identify their chemical composition such as oxide composition, alkali content, lose on ignition and moisture content of the ceramic samples .The chemical composition of the two ceramic samples of CCS01 and CCS02 are shown in Appendix F6.1 and F6.2.

i. Major oxide composition

The result of the major oxides composition is similar to the chemical composition of basaltic rock with relatively higher SiO₂ and lower Fe₂O₃ contents. The oxide composition shows that SiO₂ content of the first ceramic sample (CCS001) is 66.26 % and that of the second ceramic sample CCS02 is 69.64 %.

$$SiO_2 + Al_2O_3 + Fe_2O_3 = 66.26 + 18.56 + 7.44 = 92.26 \% \text{ for CCS01}$$

$$SiO_2 + Al_2O_3 + Fe_2O_3 = 69.64 + 18.21 + 5.14 = 92.99 \% \text{ for CCS02}$$

ASTM C618 (Standard specification for coal fly ash and raw or calcined natural Pozzolana for use as a mineral admixture in concrete) recommends the materials in order to be classified as Class N Pozzolana the SiO₂ + Al₂O₃ + Fe₂O₃ content should be above 70% [60].

Therefore according to ASTM C 618 specification, the two samples CCS01 and CCS02 satisfy the requirement and can be classified as raw Class N Pozzolana based on their chemical composition. The test result for major oxides compositions are shown in Appendix F.

ii. Alkali and Moisture Content

Alkali in natural Pozzolanas may cause alkali silica reactions, which are potentially damaging only if they cause substantial expansion and thus breaking of concrete, resulting in strength loss. Controlling the creation of such responses according to ASTM C 618 in Table 3.9 below, the maximum alkali level in terms of equivalent Na₂O percent is 1.5 % [60]. The equivalent Na₂O content of natural Pozzolana is determined using ASTM C 311, in equation 3.1 below [61].

$$\text{Equivalent Na}_2\text{O (\%)} = \text{Na}_2\text{O (\%)} + 0.658 \times \text{K}_2\text{O (\%)} \dots\dots\dots [\text{Eq 3.1}]$$

For this particular study the Na₂O and K₂O content of CCS01 are 0.48% and 0.01% respectively, and for sample CCS02 are 0.18% and 2.02 % respectively.

$$\text{Equivalent Na}_2\text{O (\%)} \text{ for CCS01} = 0.48\% + 0.658 \times 0.01\% = 0.49\%$$

$$\text{Equivalent Na}_2\text{O (\%)} \text{ for CCS02} = 0.18\% + 0.658 \times 2.02\% = 1.5\%$$

From the results above it shows that both samples CCS01 and CCS02 have alkali content of 0.49% and 1.5% respectively, therefore since the two samples have alkali content which is less than that of ASTM C618, the ceramic sample has Class N Pozzolana characteristics from chemical requirements point of view.

The moisture content of natural Pozzolana is specified by ASTM C 618 to be no more than 3% by weight of natural Pozzolanas. The moisture content of CCS01 and CCS02 was examined in this study and found to be 0.1 % and 0.37 %, respectively, which is less than the maximum stipulated value, satisfying the requirement.

iii. Lose on Ignition

The recommended maximum content for class N Pozzolana is 10%, according to ASTM C618. The LOI for CCS01 and CCS02 in this investigation was 0.43 % and 0.55 %, respectively. As a result, CCS01 and CCS02 meet the ASTM C 618 standard.

Table 3.9 ASTM C618 chemical requirement for Pozzolanas.

Chemicals	Pozzolana Class		
	N	F	S
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃ (min %)	70	70	70
MgO (max %)	5	...	5
Fe ₂ O ₃ (max %)	4	5	4
Moisture content (max %)	3	3	3
Loss on ignition (max %)	10	12	10
Available alkalis as Na ₂ O (max %)	...	1.5	1.5

3.4.5 Water

The water used for mixing the concrete in this research was pure tap water supplied by Addis Ababa Water and Sewerage Authority found in the material laboratory of Addis Ababa Institute of Technology.

CHAPTER 4 EXPERIMENTAL PROGRAM

4.1 Introduction

The mix proportion selection is process of selecting suitable concrete materials and determining their relative quantities with the goal of creating as economically as feasible concrete with specific minimum qualities.

4.2 Concrete mixes preparation

In this experimental study two types of grades of concrete, C20 and C25 were prepared to test. A total of 8 types of mixes were produced for the two grades of concrete. The natural coarse aggregate was partially replaced with crushed ceramic tiles aggregate at 10%, 20%, and 30% by weight. In addition, a control mixes were produced for the two grades of concrete, for the purpose of comparing the test results with the samples prepared by partially replacing the coarse aggregate with the crushed ceramic. The mix design was done according to ACI method.

The proportions of the basic ingredients (cement, fine aggregate, and water) in the control mix and the concrete produced by partially replacing crushed ceramic were the same, with the exception of replacing the coarse aggregate with adjusted weight of recycled ceramic. The experiment prepared C20 and C25 grades of concrete; these grades were chosen because they are commonly used grades of concrete in Ethiopian construction industry, especially C25 grade concrete.

The study used 72 concrete test cubes for compressive strength testing, 24 concrete cylinders for splitting tensile strength testing, and 24 beams for flexural strength testing for both C20 and C25 grades of concrete.

Each concrete mix was subjected to the following tests:-

1. Slump test (workability test)
2. Unit weight
3. Compressive strength test at 7th, 14th, and 28th days.
4. Splitting tensile strength test at the 28th day and
5. Flexural strength test at the 28th day were tested.

4.3 Laboratory Test Procedures

4.3.1 Mixing and Casting

Concrete is mixed in the laboratory using either a hand or a machine mixer in accordance with the ASTM C192 standard. Under controlled room temperature and humidity, freshly mixed concrete takes about 10 minutes to mix. In this study, concrete ingredients are tested, supplied separately, and mixed using a mixer machine.

It is critical that the mix ingredients are properly mixed so that fresh concrete is produced with the surface of all aggregate particles coated with cement paste, is homogeneous on the macro scale, and thus has uniform properties. Thorough mixing is required for the complete blending of the materials needed to produce homogeneous, uniform concrete. The type of mixer used is a pan type mixer, as shown in Figure 4.1 below, which can be found at Addis Ababa University Institute of Technology material Laboratory.



Figure 4.1 Pan Type Concrete mixer

4.3.2 Curing of concrete specimen

Curing is primarily intended to keep concrete moist by preventing moisture loss from the concrete while it is gaining the intended strength. After 24 hours of casting, the casted specimens were demolded and cured inside a water tanker according to ASTM C 192/C 192M until the respective testing dates of 7, 14 and 28 days.

4.3.3 Workability Test

The replacement of coarse aggregate with crushed ceramic waste aggregate was done at 10%, 20%, and 30% for both C20 and C25 concrete grade. The procedure followed to test is according to ASTM C 181. The slump cone was washed with water. Holding the slump cone down firmly the cone was filled one third with concrete and compacted 25 times with metal tapping rod. Two additional layers were added to fill the cone; each compacted 25 times as previous layer. The extra concrete are removed using a steel float. Finally, the cone is lifted vertically and the slump is measured vertically using a measuring tape as shown the figure 4.2 below [42].



Figure 4.2 Workability test of concrete.

4.3.4 Compressive strength test

Compressive strength test was performed in accordance with procedure according to ASTM C39/C39M as described in Construction materials laboratory manual [42]. For the tests, 150x150x150 mm cube specimens were used. This test was performed to confirm whether the targeted 7th, 14th and 28th day compressive strength for both normal and concrete having ceramic waste aggregate concrete were achieved. The strength characteristics of each cube were determined on Universal Testing Machine at a loading rate of 120 kN/min. Three specimens for each mix were tested at each curing age and the values of the crushing load were averaged and used to evaluate the mean strength for each batch. A total of 36 cube samples for C20 grade concrete and 36 cube samples for C25 grade concrete were prepared.

The concrete sample cubes were loaded to failure using a digital compressive strength testing machine as show in the figure 4.3 below and the failure load is recorded .The stress is computed by dividing the failure load by surface area of the sample cube concrete.



Figure 4.3 Universal Testing Machine setup for Compression Strength Test.

4.3.5 Tensile Strength Test

Inorde to asses the tensile strength charactrestis of concrete samples produced with coarse aggregate partiallly replaced with ceramic waste aggregtae , the splitting tensile strength test was conducted on 150x300mm concrete cylinder specimens in accordance with the provision of ASTM C496.The splitting strengths were determined on Universal Testing Machine at a loading rate of 120 kn /min until failure.The splitting tensile strength (Ts) was then calculated as follows :

$$T_s = \frac{2P}{\pi ld} \dots \dots \dots \text{(Eq 4.1)}$$

In the equation above, Ts is the splitting tensile stress (Kn/m²), P is the maximum applied load by the testing machine (Kn), l is the length of the cylinder specimen (m), and d is the diameter of the cylinder specimen (m).The splitting tensile strength is shown in the figure 4.4 below.



Figure 4.4 Universal Testing Machine setup for Splitting Tensile Strength Test.

4.3.6 Flexural Strength of Concrete

The Flexural strength is the measurement of the capacity of the concrete to withhold deformation under flexural load .It signifies the maximum stress experienced within the concrete at collapse load. In this test, the sample concrete beam is subjected to a bending force applied downward on a member supported at its two ends.

The corresponding concrete beam samples of size 50cm *10cm*10cm were made for each percentage of coarse aggregate replacement including the control mix. The concrete was poured into the molds and placed on electric plate vibrator to remove the air bubbles. The concrete sample was removed from the mold after 24 hours and cured inside a water tank for 28 days. The specimen was loaded according to ASTM C 78 (third –point loading) as shown in the figure 4.5 below until it failed. The failure load for each concrete grade was recorded and the stress at failure is calculated.



Figure 4.5 Universal Testing Machine setup for Flexural Strength Test.

4.4 Quantities of materials

The quantities of the concrete-making ingredients (cement, water, and aggregates) were measured by weight, as was the partial replacement of coarse aggregate with recycled crushed ceramic. The volume of test specimens were first calculated as shown in the Table 4.1 below in order to compute the volume of single concrete mix.

Table 4.1 Total volume of concrete for single concrete mix.

Type of concrete sample	Calculations
Cubes (compressive strength)	$9*(0.15*0.15*0.15) \text{ m}^3 = 0.03 \text{ m}^3$
Cylinder (splitting tensile strength)	$3*(3.14*0.075^2*0.3) = 0.016 \text{ m}^3$
Beams (flexural strength)	$3*(0.5*0.1*0.1) \text{ m}^3 = 0.015 \text{ m}^3$
Total volume of concrete	$(0.03 + 0.016 + 0.015) \text{ m}^3 = 0.061 \text{ m}^3$
Total volume of concrete + 10% wastage	$(0.061 + 10% * 0.061 \text{ m}^3) = 0.067 \text{ m}^3$

An additional 10% was calculated to account for the compaction factor and any waste that may occur during the mixing and casting processes. Finally, the volume of concrete required for each concrete mix was 0.067 m^3 as computed above. Tables 4.2 and 4.3 below show the material proportions for 0.067 m^3 of C20 and C25 grade concrete, respectively.

To reduce the number of variables that would be impacted by the replacement of coarse aggregate with ceramic waste, precautions were taken. New, unmixed ceramic floor and wall tiles were used to study the effects of material replacement with single material. By measuring the proportions of the material from different sizes and adhering to the plan to minimize variables, the natural aggregate grading curve was matched with the substituted ceramics.

The ceramic waste used have a bulk density of 1214 kg/m^3 as computed in the laboratory, which is lower by 29.95% than the density of natural coarse aggregate, which is 1662 kg/m^3 . In order to have a better match the total aggregate volume and number of aggregate particles (including natural voids) as the natural aggregate being replaced, a proportioning adjustments was made by multiplying the aggregate mass replaced by a factor. This is done to keep the ratio of cement paste to aggregate uniform and the aggregates evenly coated with paste. The density adjustment factors were calculated by dividing the density of the

replacement aggregate by the density of the natural aggregate, as shown in equation 4.3 and equation 4.4 below [62].

$$F = \frac{\rho_c}{\rho_n} \dots\dots\dots (Eq 4.3)$$

$$M_C = R_C * M_a * F \dots\dots\dots (Eq 4.4)$$

Where:-

F = density adjustment factor used compute weight of replaced ceramic (unit less)

ρ_c = density of ceramic coarse aggregate (kg /m³)

ρ_n = density of natural coarse aggregate (kg /m³)

M_C = mass of ceramic coarse aggregate to be added (kg)

R_C = ratio of ceramic aggregate replacement (%)

M_a = mass of natural coarse aggregate required in the original mix design (kg)

Table 4.2 Amount of ingredients for C20 concrete [Appendix B2.1].

4.2 a) Amount of ingredients for 1m³ concrete.

Code	Concrete grade (Mpa)	w/c	Water (kg)	Cement (kg)	Fine agg. (kg)	Coarse agg. (kg)	Ceramic agg (kg)
C20C00	20	0.64	194	303	878	949	0
C20C10	20	0.64	194	303	878	854.10	69.32
C20C20	20	0.64	194	303	878	759.20	138.64
C20C30	20	0.64	194	303	878	664.30	207.96

4.2 b) Amount of ingredients for 0.067 m³ concrete.

Code	Concrete grade (Mpa)	w/c	Cement (kg)	Water (kg)	Fine agg. (kg)	Coarse agg. (kg)	Ceramic Agg (kg)
C20C00	20	0.64	13.00	20.30	58.83	63.58	0
C20C10	20	0.64	13.00	20.30	58.83	57.22	4.64
C20C20	20	0.64	13.00	20.30	58.83	50.87	9.29
C20C30	20	0.64	13.00	20.30	58.83	44.51	13.93

Table 4.3 Amount of ingredients for C25concrete [AppendixB2.2].

4.3 a) Amount of ingredients for 1m³ concrete.

Code	Concrete grade (Mpa)	w/c	Water (kg)	Cement (kg)	Fine agg. (kg)	Coarse agg. (kg)	Ceramic agg (kg)
C25C00	25	0.58	206	355	844	954	0
C25C10	25	0.58	206	355	844	858.60	69.68
C25C20	25	0.58	206	355	844	763.20	139.37
C25C30	25	0.58	206	355	844	667.80	209.05

4.3 b) Quantities of material for 0.067 m³ concrete.

Code	Concrete grade (Mpa)	w/c	Water (kg)	Cement (kg)	Fine agg. (kg)	Coarse agg. (kg)	Ceramic agg (kg)
C25C00	25	0.58	13.80	23.78	56.55	63.92	0
C25C10	25	0.58	13.80	23.78	56.55	57.53	4.67
C25C20	25	0.58	13.80	23.78	56.55	51.13	9.34
C25C30	25	0.58	13.80	23.78	56.55	44.74	14.01

In all mixes the same quantity of cement, sand, and water has been used in concrete composition except coarse aggregate quantity. The quantity of coarse aggregates was changed according to the percentage replacement of coarse aggregate with ceramic waste aggregate. The nomenclatures (codes) used in Table 4.2 and Table 4.2 above are presented below:-

C20C00 = C20 concrete with cement, sand, 100 % coarse aggregate and 0% ceramic

C20C10 = C20 concrete with cement, sand, 90 % coarse aggregate and 10% ceramic

C20C20 = C20 concrete with cement, sand, 80 % coarse aggregate and 20% ceramic

C20C30 = C20 concrete with cement, sand, 70 % coarse aggregate and 30% ceramic

C25C00 = C25 concrete with cement, sand, 100 % coarse aggregate and 0% ceramic

C25C10 = C25 concrete with cement, sand, 90 % coarse aggregate and 10% ceramic

C25C20 = C25 concrete with cement, sand, 80 % coarse aggregate and 20% ceramic

C25C30 = C25 concrete with cement, sand, 70 % coarse aggregate and 30% ceramic

Note: - In the above nomenclatures both C20C00 and C25C00 are the reference (control mixes) for the respective concrete grades.

CHAPTER 5 TEST RESULTS AND DISCUSSIONS

5.1 Introduction

This section discusses the laboratory test results of experiment conducted to investigate the fresh and hardened characteristics of concrete made by partly substituting coarse aggregate with crushed waste ceramic tiles and comparing the outcomes to a reference sample. The findings of slump, compressive strength, splitting tensile strength, and flexural strength tests for C20 and C25 concrete grades are presented in this section of the study. Furthermore, economic investigation is carried out for the two grades of concrete.

5.2 Concrete Test Results

5.2.1 Fresh Concrete Test Results

a) Workability

The quantity of useful internal effort required to create full compaction is referred to as workability. The effort or power needed to control the internal friction amongst the discrete units in the concrete is a physical feature of concrete alone. Workable concrete has less internal friction between the particles or overcomes the frictional resistance provided by the formwork surface or reinforcement incorporated in the concrete with a minimal amount of compacting effort.

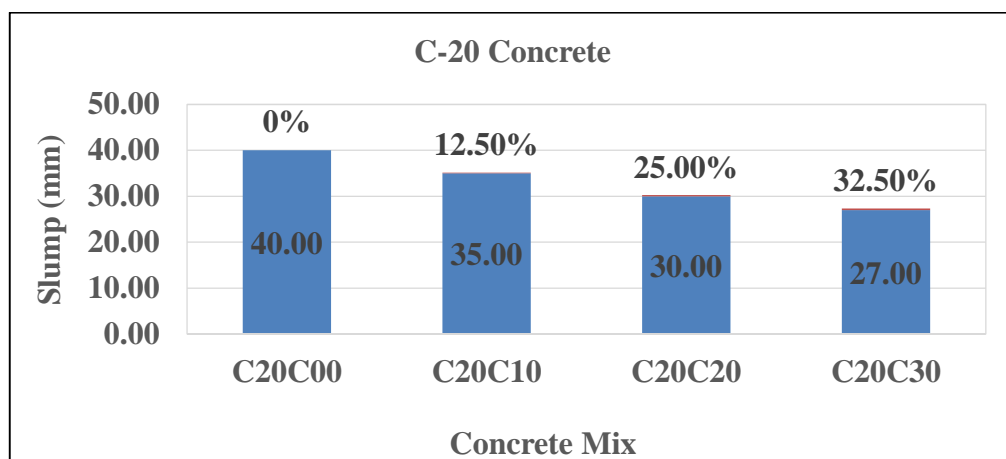
The fresh concrete qualities, slump test, and fresh concrete density tests are evaluated for each concrete mixture containing 0%, 10%, 20%, and 30% addition of crushed waste ceramic coarse aggregate by weight of concrete. Table 5.1 below shows slump and fresh concrete densities of each concrete mix.

Table 5.1 Slump and fresh concrete density test result

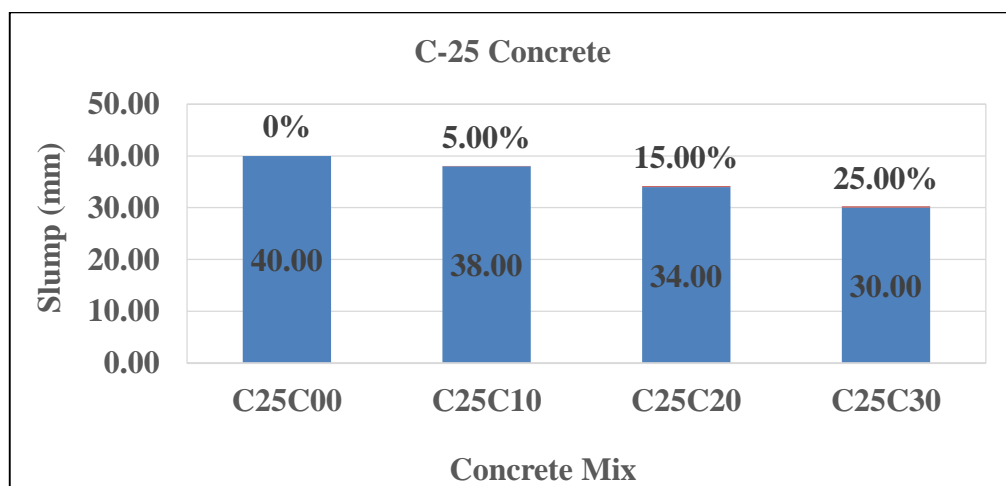
No	Code	Grade of Concrete (Mpa)	% of Ceramic	Slump (mm)	Fresh concrete density (kg /m ³)
1	C20C00	20	0	40	2305.00
2	C20C10	20	10	35	2300.16
3	C20C20	20	20	30	2292.78
4	C20C30	20	30	27	2274.80
1	C25C00	25	0	40	2310.00
2	C25C10	25	10	38	2305.52
3	C25C20	25	20	34	2287.59
4	C25C30	25	30	30	2284.36

According to ACI, all of the mixes used in this study were designed to have slump ranging from 25mm to 75mm. The slump test findings for both concrete grades were greater than 25mm and less than 75mm, putting them within the standard's permitted range. Hence, don't cause workability problem with the amount of ceramic waste used in the experiment.

Slump test results for mixes C20C10 (mix with 10% ceramic), C20C20 (mix with 20% ceramic), C20C30 (mix with 30% ceramic) from Table 5.1 and on figure 5.1 shows 12.5%, 25% and 32.5 % reduction in slump value for C20 concrete grade respectively. On the other hand for C25 concrete grade mixes C25C10 (mix with 10% ceramic), C25C20 (mix with 20% ceramic), C25C30 (mix with 30% ceramic) the slump value reduced 5%, 15% and 25 % respectively as shown below in figure 5.1. These decrease in slump values for both grades of concrete can be attributed to higher water absorption capacity and the angular shape of the ceramic waste.



5.1 (a)

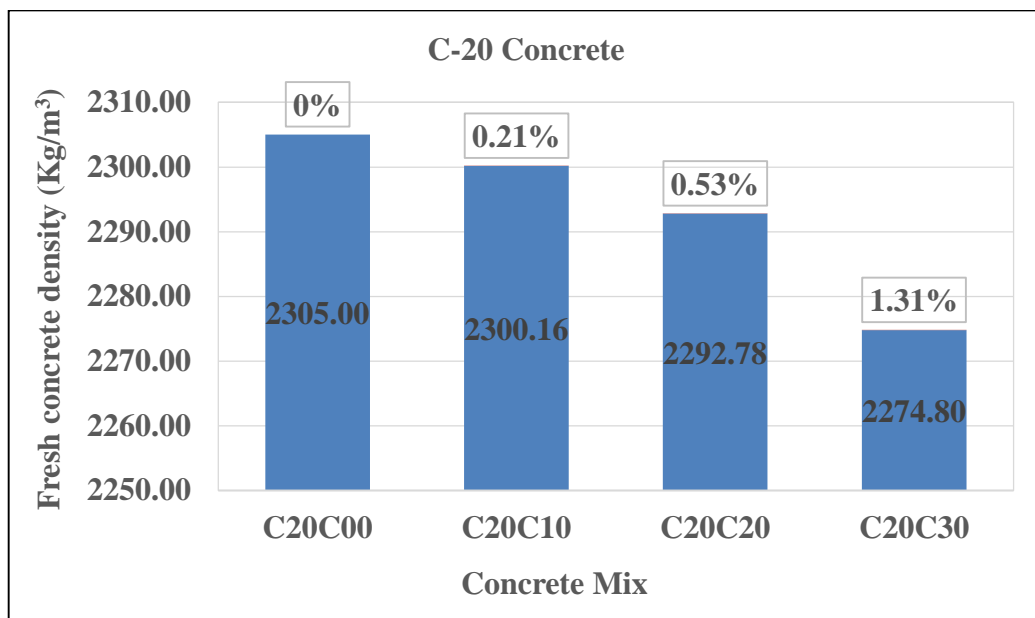


5.1 (b)

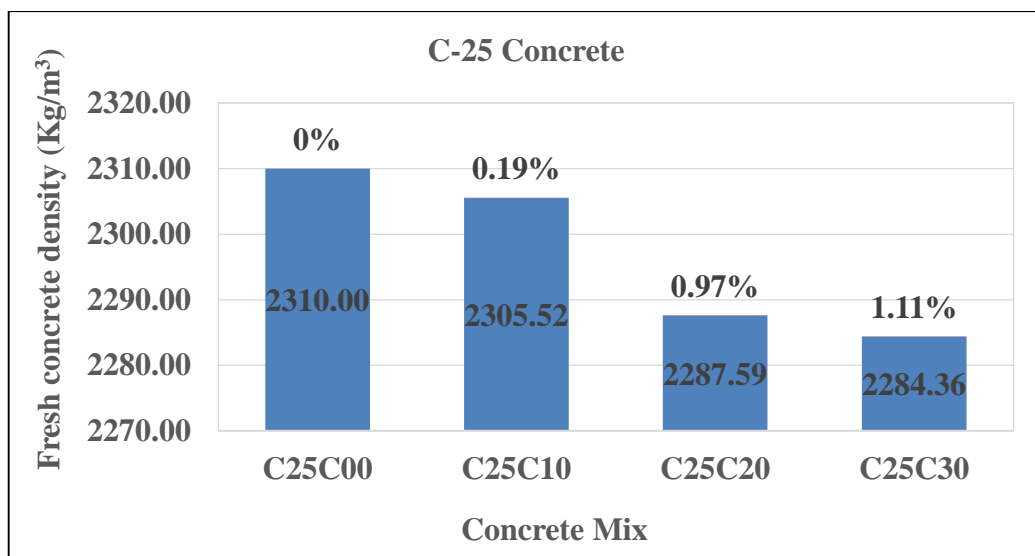
Figure 5.1 Slump test results

b) fresh concrete density

Fresh concrete density for C20 concrete grade mixes C20C10 (mix with 10% ceramic), C20C20 (mix with 20% ceramic), C20C30 (mix with 30% ceramic) when compared to the control mix, it reduced 0.21%, 0.53 % and 1.31 % respectively .On the other hand, for C25 concrete grade mixes of C25C10 (mix with 10% ceramic), C25C20 (mix with 20% ceramic), C25C30 (mix with 30% ceramic) the fresh density decreased 0.41%, 0.97% and 1.11 % respectively as shown in figure 5.2 below.



5.2 (a)



5.2 (b)

Figure 5.2 Fresh concrete test result

5.2.2 Hardened Concrete Test Results

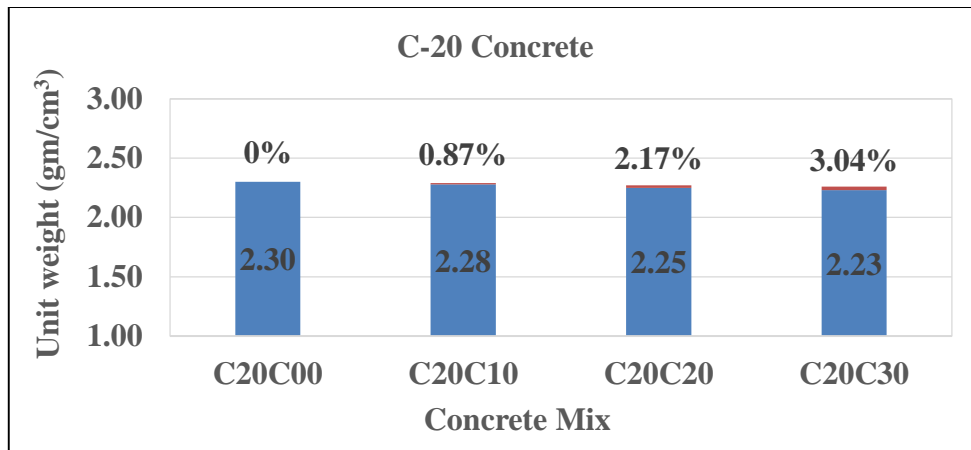
In order to investigate the hardened properties of concrete, the tests conducted for this experiment are hardened density, compressive strength, splitting strength and flexural strength.

a) Density of Concrete

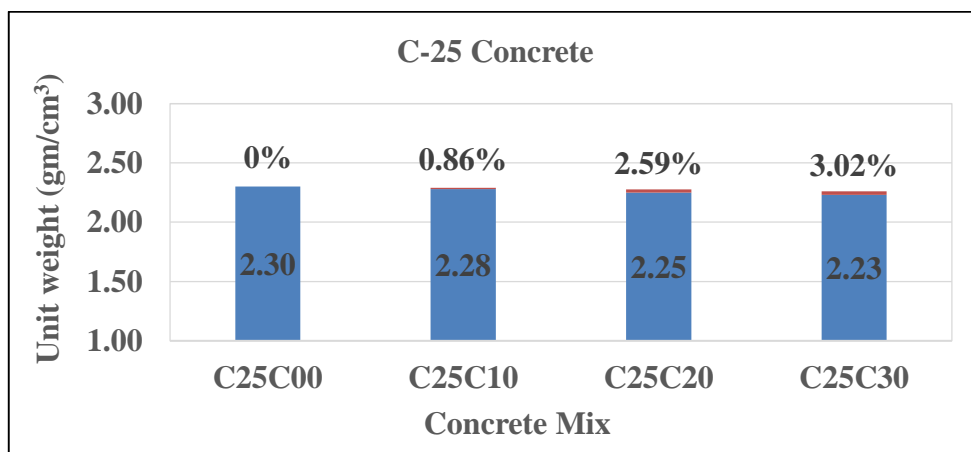
Concrete's properties change as it strengthens with days. The unit weights of the hardened concrete samples are described in this section. Prior to the compressive strength test, the concrete cubes' sizes, and weights were determined. These examinations were conducted after 7, 14, and 28 days. The attached appendix C3 contains the detailed findings for weight and dimensions. The outcomes of the concrete samples unit weight calculations in this section, however, were only computed using the 28-day weight and dimension. The findings of unit weight and percent reduction for various percent substitutions of natural coarse aggregate with crushed waste ceramic tiles are shown in Table 5.2 and Figure 5.3 below.

Table 5.2 Unit weights of concrete with and without waste ceramic aggregate.

.No.	Code	Ceramic Substitution (%)	Unit weight (gm/cm ³)	Unit weight reduction (%)
1	C20C00	0	2.30	0.00
2	C20C10	10	2.28	0.87
3	C20C20	20	2.25	2.17
4	C20C30	30	2.23	3.04
1	C25C00	0	2.32	0.00
2	C25C10	10	2.30	0.86
3	C25C20	20	2.26	2.59
4	C25C30	30	2.25	3.02



5.3 (a)



5.3 (b)

Figure 5.3 Unit weight of concrete mixes (gm/cm³).

Table 5.2 and Figure 5.3 above presents the density of concrete mixes with and without ceramic tiles after 28 days. The experimental outcomes indicated that the density of the concrete with the introduction of 10%, 20% and 30 % ceramic tiles achieved 0.87 %, 2.17 % and 3.04 % reduction in concrete density for C20 grade concrete respectively and on the other hand for C25 grade concrete the density reduced 0.86 %, 2.59 % and 3.02 %, for 10%, 20% and 30 % replacement respectively .It was detected that density is reduced as the quantity of ceramic tiles increases in concrete. This happens due to low specific gravity of ceramic waste aggregate as compared to with natural coarse aggregate.

b) Compressive Strength Test Result

I. C20 Concrete Grade

Compressive strength tests were performed on the 7th, 14th, and 28th days. The compressive strength test results at the 7th, 14th, and 28th days are shown in Table 5.3 below [Appendix

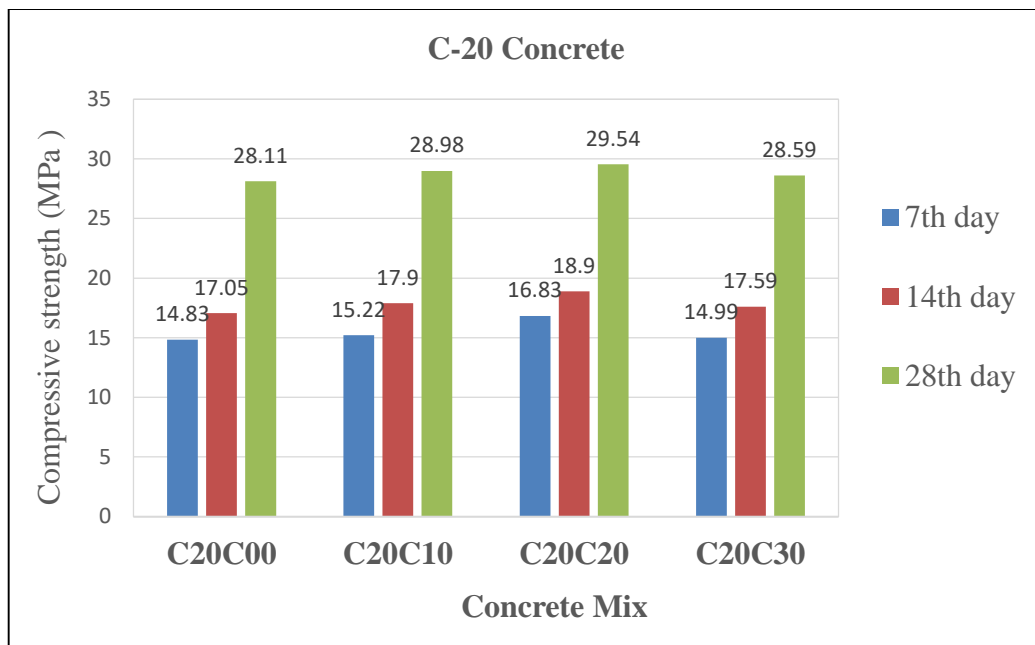
C3.1, C3.2, C3.3, and C3.4]. The compressive strength of C20 concrete improved as the amount of crushed waste ceramic increased. The results of the tests indicated that the addition of crushed waste ceramic at 10%, 20% and 30%. The compressive strength increased when compared to the control mix. The results reveal that replacing 20% of the coarse aggregate with sieved and graded waste ceramic gains the maximum compressive strength at the 7th, 14th, and 28th days.

Table 5.3 Compression strength of C20 concrete with ceramic waste aggregate

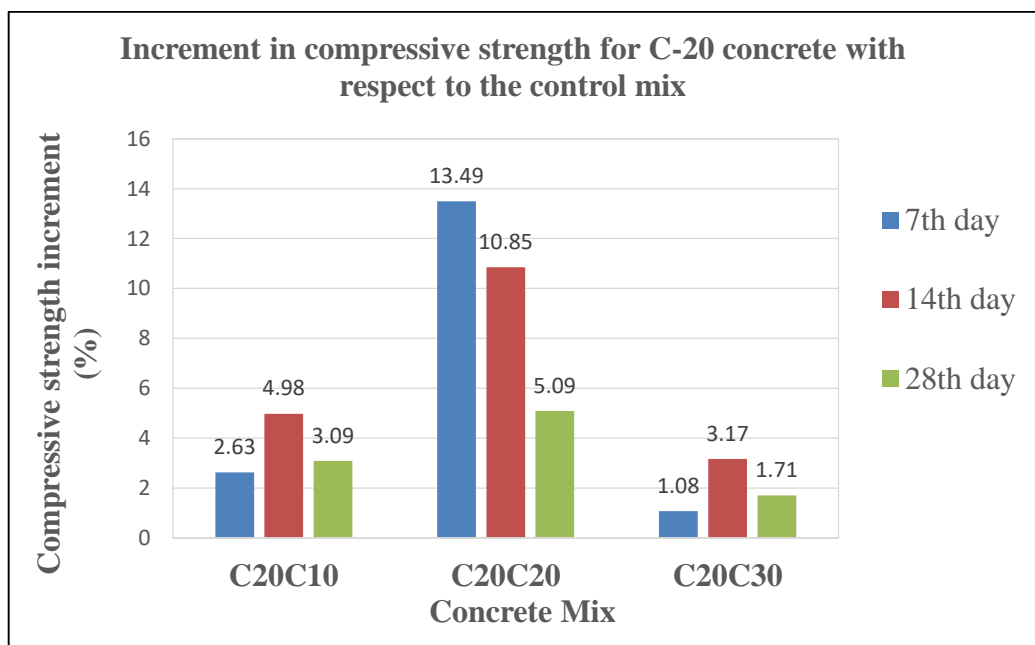
No	Code	Ceramic (%)	Compressive Strength (Mpa)			% Strength increase		
			7 th day	14 th day	28 th day	7 th day	14 th day	28 th day
1	C20C00	0	14.83	17.05	28.11	0.00	0.00	0.00
2	C20C10	10	15.22	17.90	28.98	2.63	4.98	3.09
3	C20C20	20	16.83	18.90	29.54	13.49	10.85	5.09
4	C20C30	30	14.99	17.59	28.59	1.08	3.17	1.71

The experiment result which is depicted below in Figure 5.2 shows that the compressive strength of the concrete specimen at the 28th days for 10%, 20 %, and 30 % coarse aggregate replacement, it increased by 3.09 %, 5.09 % and 1.71 % respectively. However, at 30% replacement the compressive strength dropped by 1.34 % and 3.21 % at the 28th days when compared to 10% and 20 % replacement respectively. The maximum strength increase is obtained by concrete specimen produced by 20% partial replacement at 7th, 14th, and 28th days.

The result show that the concrete mixes containing crushed ceramic waste aggregates achieve the compressive strength levels between 10 to 30 % compared to the conventional concrete. This indicates that the crushed ceramic waste has a potentially to be used as coarse aggregates for concrete.



5.4 (a)



5.4 (b)

Figure 5.4 Compression strength of C20 Concrete with ceramic waste aggregate

II. C25 Concrete Grade

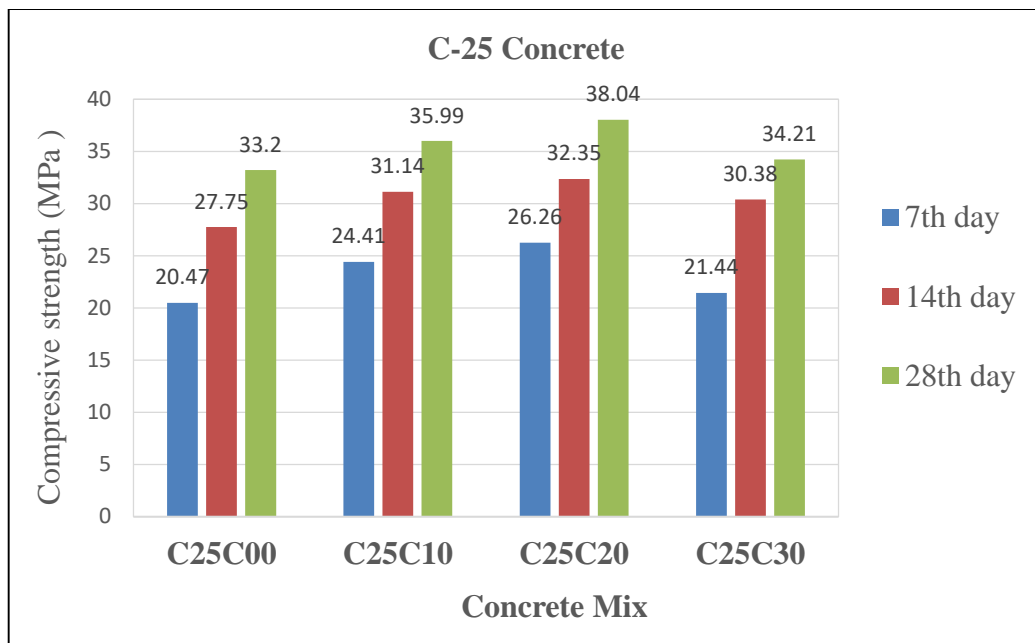
Compressive strength tests were performed on the 7th, 14th, and 28th days. The compressive strength test results at the 7th, 14th, and 28th days are shown in Table 5.4 below [Appendix

C3.5, C3.6, C3.7, and C3.8]. The compressive strength of C25 concrete improved as the amount of crushed waste ceramic increased. The results of the tests demonstrated that the addition of crushed waste ceramic at 10% .20% and 30% the compressive strength increased when compared to the control mix. The results reveal that replacing 20% of the coarse aggregate with crushed waste ceramic results the highest compressive strength at the 7th, 14th, and 28th days.

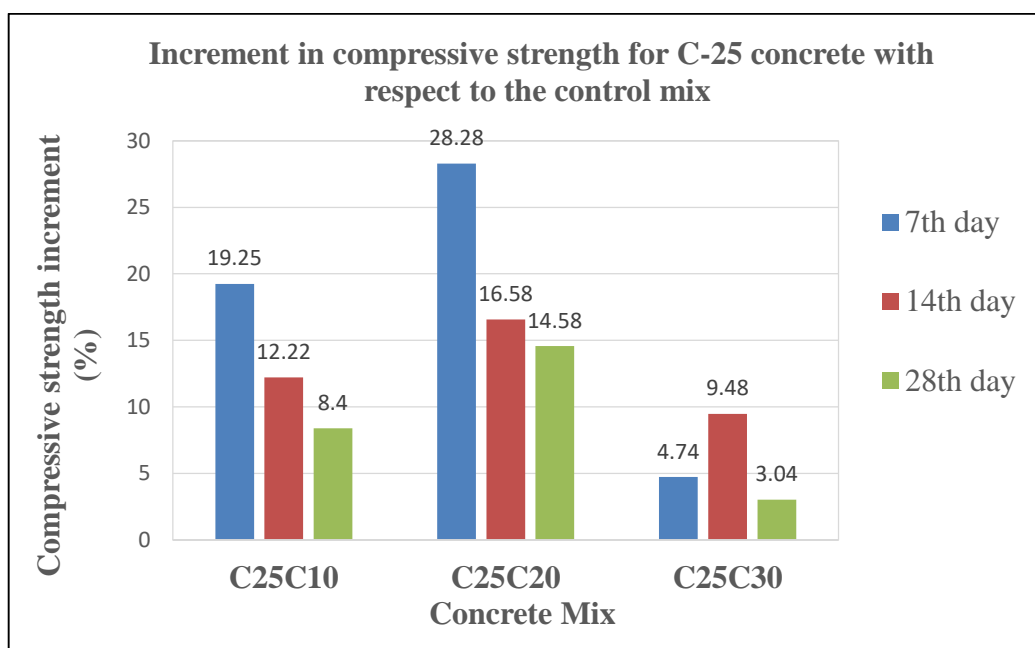
Table 5.4 Compression strength of C25 concrete with ceramic waste aggregate

No	Code	Ceramic (%)	Compressive Strength (Mpa)			% Strength increment		
			7 th day	14 th day	28 th day	7 th day	14 th day	28 th day
1	C25C00	0	20.47	27.75	33.20	0.00	0.00	0.00
2	C25C10	10	24.41	31.14	35.99	19.25	12.22	8.40
3	C25C20	20	26.26	32.35	38.04	28.28	16.58	14.58
4	C25C30	30	21.44	30.38	34.21	4.74	9.48	3.04

The test outcome which is depicted below in Figure 5.5 shows that the compressive strength of the concrete specimen at the 28th days for 10%, 20 %, and 30 % coarse aggregate replacement, it increased by 8.40 %, 14.58 % and 3.04 % respectively. However, at 30% replacement the compressive strength starts to decrease when compared to 10% and 20 % replacement. The maximum strength result is obtained by concrete samples made at 20% partial replacement at 7th, 14th, and 28th days.



5.5 (a)



5.5 (b)

Figure 5.5 Compression strength of C25 Concrete with ceramic waste aggregate.

c) Flexural Strength Test Result

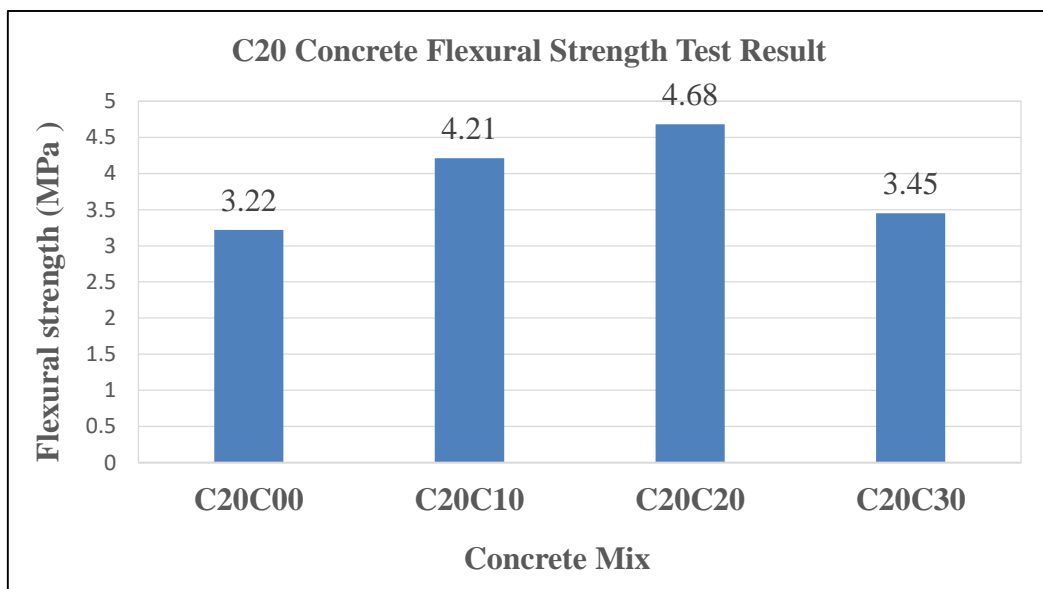
I. C 20 Concrete

At the 28th day, the flexural strength test was performed. As depicted in Table 5.5 below [Appendix D4.1], all of the outcomes of the test samples produced by partly substituting coarse aggregate with waste ceramic tiles are greater than the strength of the reference mix. As the percentage of recycled waste ceramic increases, so did the flexural strength.

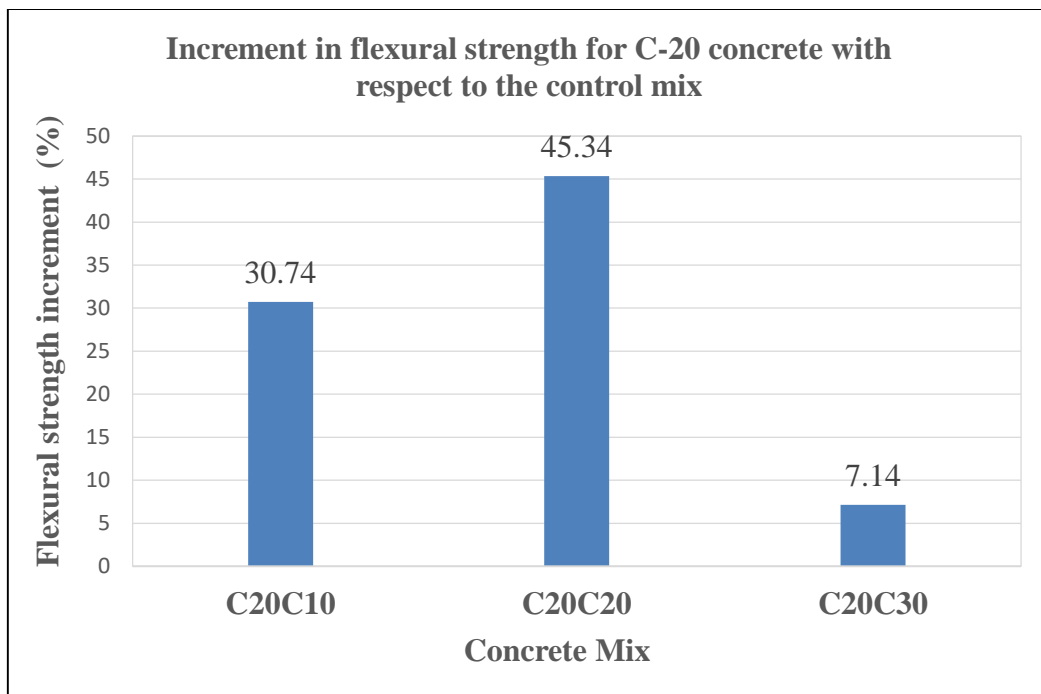
Table 5.5 Flexural strength of C20 concrete with ceramic waste aggregate

Code	Ceramic (%)	Flexural Strength (Mpa)	% strength increase compared to reference mix
C20C00	0	3.22	0.0
C20C10	10	4.21	30.74
C20C20	20	4.68	45.34
C20C30	30	3.45	7.14

The graphical representation in Figure 5.6 below demonstrates that the samples made with 20 % partial substitution attains the highest value, while the mixes made with 0% partial replacement achieves the smallest value. The samples with 10%, 20%, and 30% partial substitution raises the flexural strength by 30.74%, 45.34%, and 7.14 %, respectively.



5.6 (a)



5.6 (b)

Figure 5.6 Flexural strength of C20 Concrete with ceramic waste aggregate

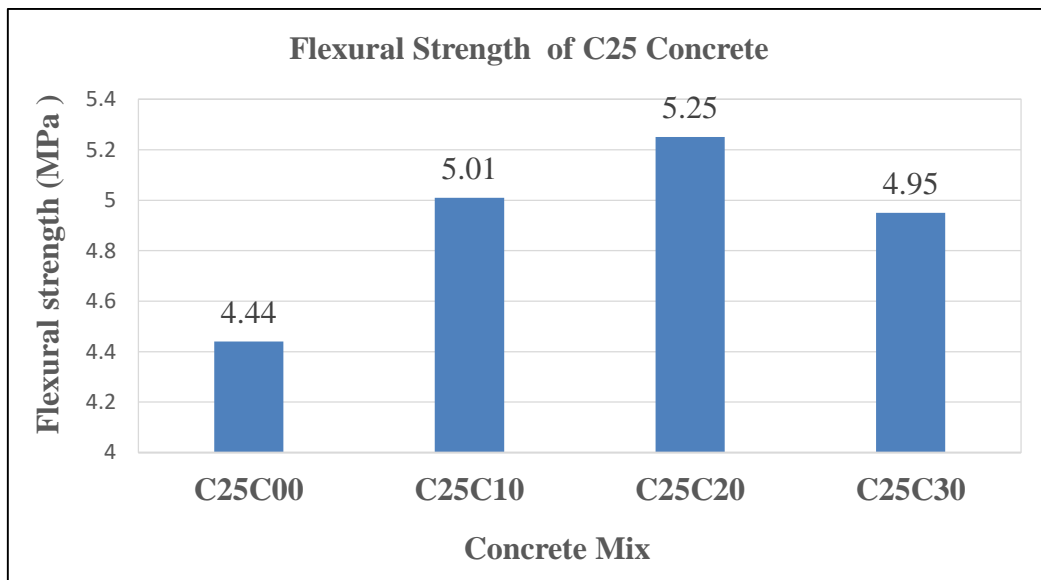
II. C 25Concrete

At the 28th day, the flexural strength test for C25 concrete was also performed. As revealed in Table 5.6 [Appendix D4.2], all of the outcomes of the samples produced by partly substituting coarse aggregate with crushed waste ceramic tiles are more than the strength of the reference samples. As the percentage of crushed waste ceramic increase, so did the flexural strength. However, at 30% replacement the strength starts to decrease as compared to 20 % replacement.

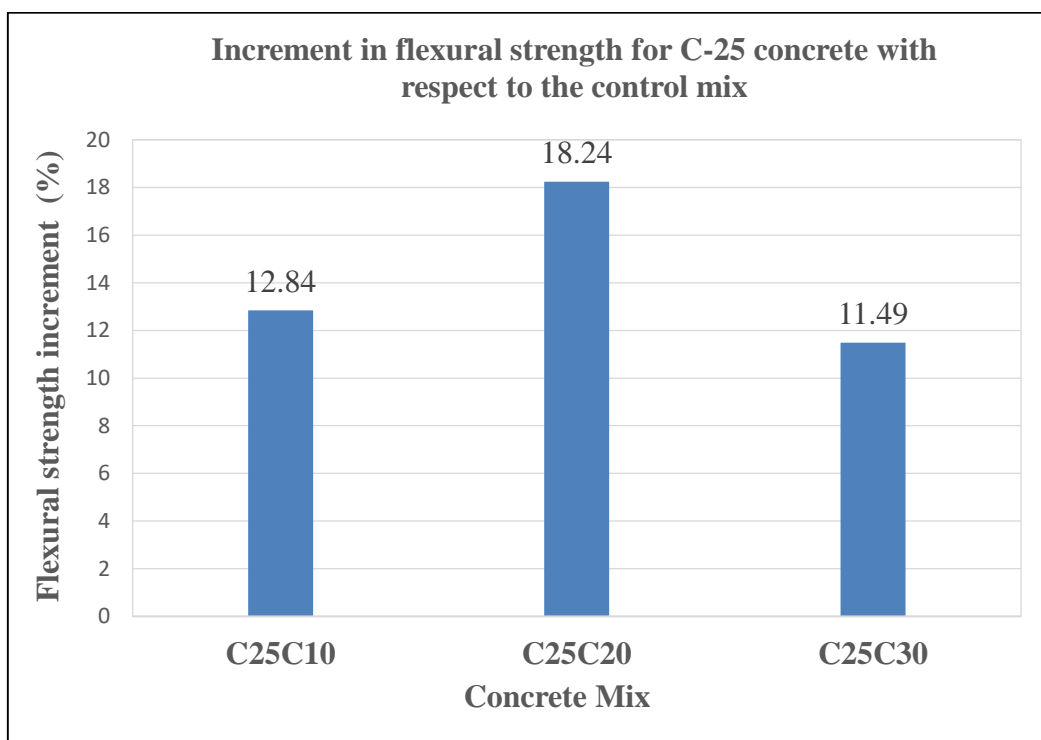
Table 5.6 Flexural strength of C25 concrete with ceramic waste aggregate.

Code	Ceramic (%)	Flexural Strength (Mpa)	% strength increase compared to reference mix
C25C00	0	4.44	0.0
C25C10	10	5.01	12.84
C25C20	20	5.25	18.24
C25C30	30	4.95	11.49

The specimen prepared with 20% partial replacement achieves the greatest value of 5.25 MPa, while the sample prepared with 0% partial replacement achieves the lowest value of 4.44 MPa. As demonstrated in figure 5.7 below, the specimen with 10%, 20%, and 30% partial replacement increases the strength by 12.84%, 18.24 %, and 11.49 %, respectively as compared to the control mix.



5.7 (a)



5.7 (b)

Figure 5.7 Flexural strength of C25 Concrete with ceramic waste aggregate

d) Splitting Tensile Strength Test Result

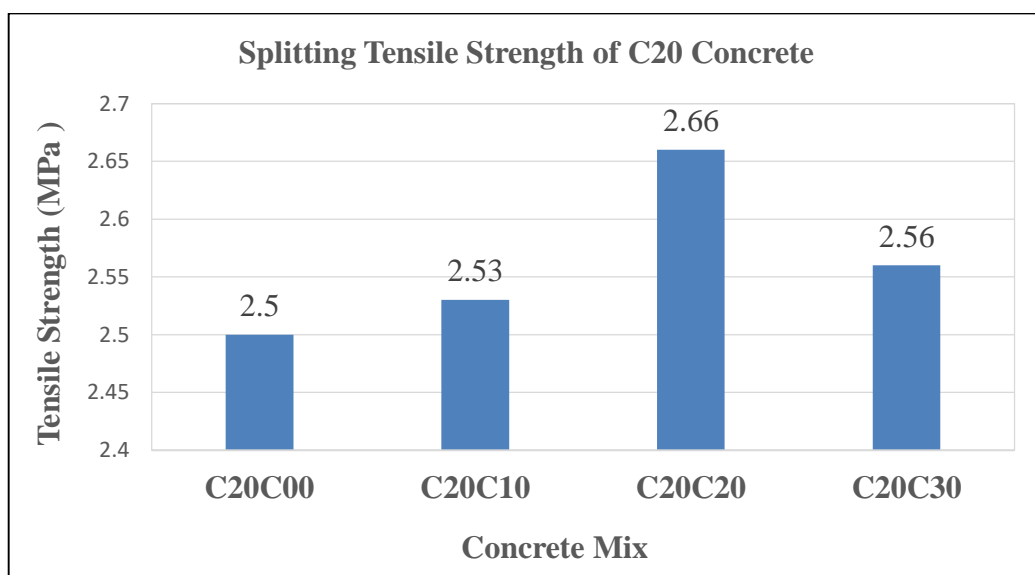
I. C 20 Concrete

The splitting tensile strength test for C20 concrete was also performed at the 28th day. All of the test specimen results obtained by partially replacing coarse aggregate with crushed waste ceramic tiles are greater than the strength of the control mix. As depicted in Table 5.7 below [Appendix E5.1], the splitting tensile strength improved somewhat as the percentage of crushed waste ceramic tiles increased.

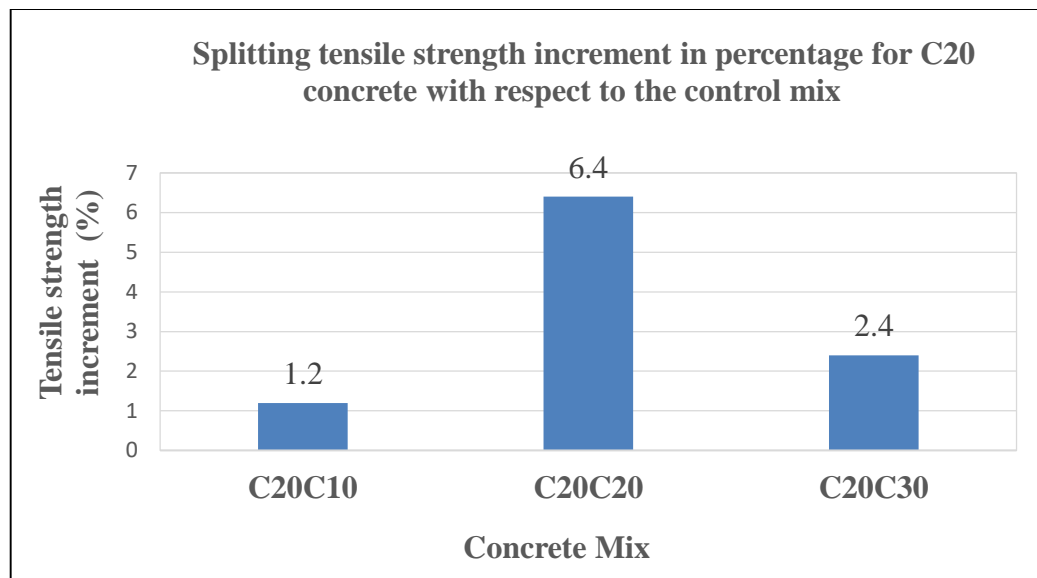
Table 5.7 Splitting Tensile Strength of C20 concrete with ceramic waste aggregate

Code	Ceramic (%)	Tensile Strength (Mpa)	% strength increment compared to reference mix
C20C00	0	2.50	0.0
C20C10	10	2.53	1.2
C20C20	20	2.66	6.4
C20C30	30	2.56	2.4

The specimen created with 20% partial replacement has the greatest value of 2.66 MPa, while the sample prepared with 0% partial replacement has the lowest value of 2.50 MPa. As demonstrated in Figure 5.8 below, the specimen with 10%, 20%, and 30% partial replacement increases in strength by 1.2% , 6.4%, and 2.4%, respectively.



5.8 (a)



5.8 (b)

Figure 5.8 Splitting tensile strength of C20 Concrete with ceramic waste aggregate

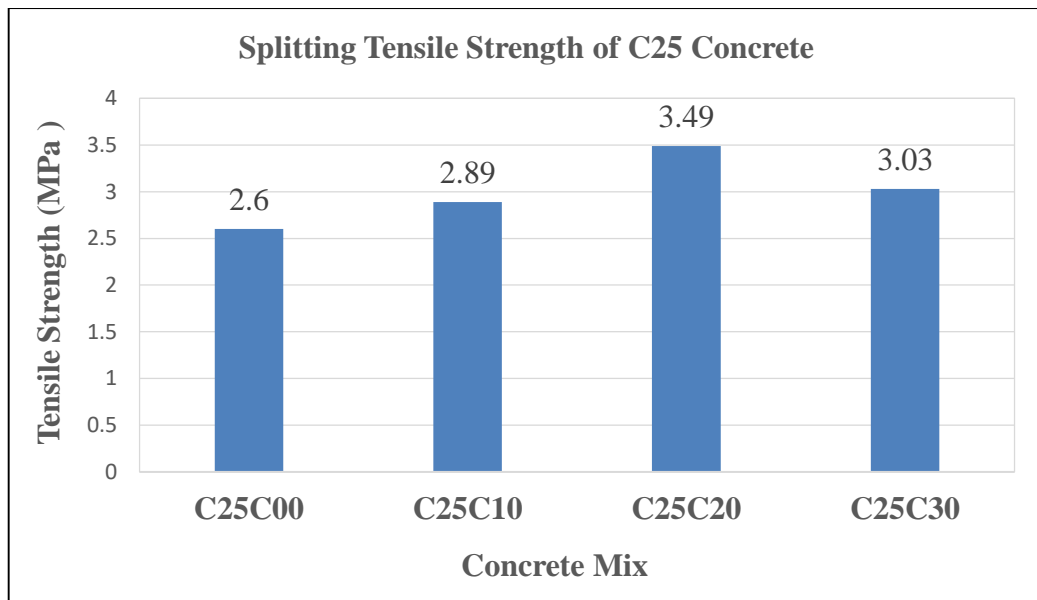
II. C 25 Concrete

At the 28th day, the splitting tensile strength test for C 25 concrete was also carry out. The strength of the experiment samples made by partly substituting coarse aggregate with crushed waste ceramic tiles is more than the strength of the reference mixes in all cases. Table 5.8 [Appendix E5.2] exhibits that as the amount of waste crushed ceramic increases, the splitting tensile strength improved significantly.

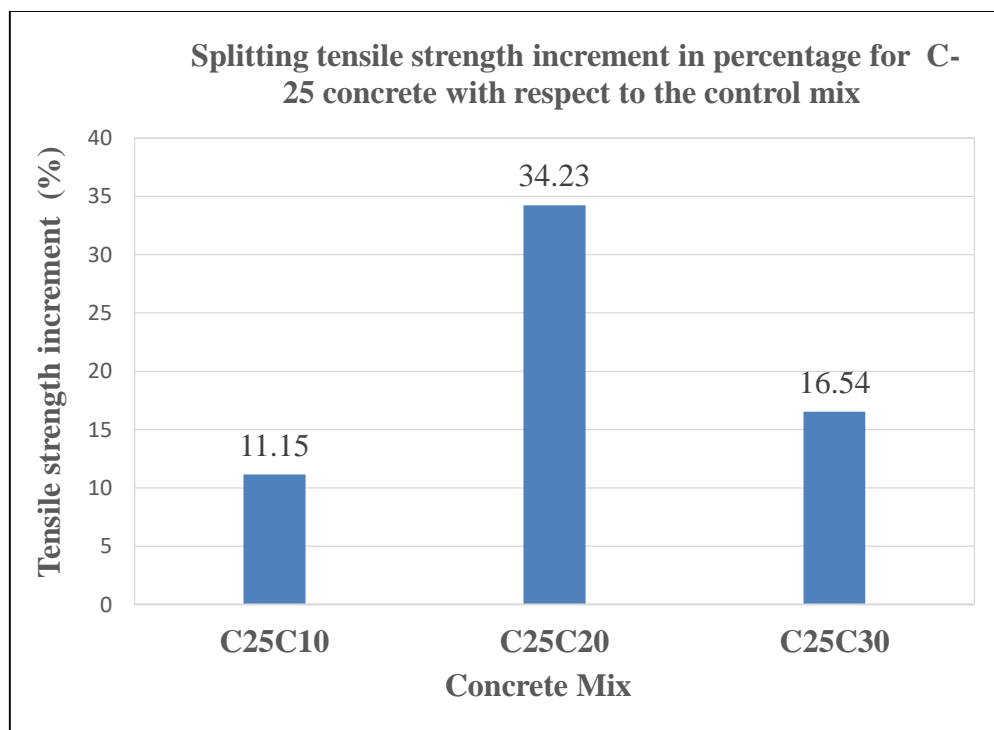
Table 5.8 Splitting Tensile Strength of C20 concrete with ceramic waste aggregate.

Code	Ceramic %	Tensile Strength (Mpa)	% strength increment compared to reference mix
C25C00	0	2.60	0.0
C25C10	10	2.89	11.15
C25C20	20	3.49	34.23
C25C30	30	3.03	16.54

The specimen prepared with 20% substitution has the maximum result of 3.49 MPa, while the sample prepared with 0% partial replacement has the lowest value of 2.60 MPa. As shown in Figure 5.9, the specimen with 10%, 20%, and 30% partial replacement increases in strength by 11.15 %, 34.23 %, and 16.54 %, respectively.



5.9 (a)



5.9 (b)

Figure 5.9 Splitting tensile strength of C25 Concrete with ceramic waste aggregate

CHAPTER 6 CONCLUSIONS AND RECCOMENDATIONS

This experiment's main objective is to investigate the characteristics of freshly-mixed and hardened concrete when coarse aggregate is partially replaced with crushed waste ceramic coarse aggregate in the making of concrete. The results of the reference specimen were evaluated by comparing to the substitution results. As a result of the findings of the research, it has been determined that the following conclusions and recommendations are made:

6.1 Conclusions

1. The results of this investigation have demonstrated that ceramic waste aggregate has the ability to partially substitute the natural coarse aggregate in concrete since its physical characteristics are fit the standard. As a result, the ceramic waste aggregate can be employed partially in the concrete mixture.
2. The workability of ceramic waste aggregate concrete drops as the proportion of natural coarse aggregate substituted with ceramic waste aggregate rises for the two classes of concrete. This is owing mostly to the increased water absorption of ceramic waste aggregate, which results in a lower water content in the mix.
3. The fresh and hardened concrete density of ceramic waste aggregate concrete decreases as the percentage of ceramic waste coarse aggregate increases. This is because ceramic waste aggregate has a lower specific gravity than the natural aggregate.
4. The experiment results indicated that for 10%, 20 %, and 30 % replacement of the natural coarse aggregate with crushed waste ceramic aggregate resulted improved compressive strength, split tensile strength and flexural strength for C20 and C25 classes of concrete. The maximum result was obtained at 20% replacement. However, the aforementioned strength tests starts to decrease at 30 % replacement when compared to the 10% and 20 % replacement. Therefore the increase in compressive strength ,split tensile strength and flexural strength for both grades of concrete can be attributed to the following factors:-
 - The irregular shape and rough surface of ceramic aggregate, which provide superior specific surface area to bond strongly with cement paste.

- The high porosity and water absorption of ceramic aggregate, which provides guaranteed cement hydration through internal curing.
- Due to high aggregate – paste bonding provided by the increased surface area of rough ceramic aggregate.

6.2 Recommendations for future studies

1. The influence of larger size waste ceramic tiles (size such as 19mm or 20 mm) on the characteristics of fresh and hardened concrete should be investigated.
2. A comparison study of concrete made with ceramic waste tiles, sanitary wares, table wares and electrical insulators from various types of ceramic waste industries should be conducted.
3. The structural performance of concrete members made with ceramic aggregates should be rigorously studied for flexure and shear.
4. More researches should be done to determine the durability of ceramic waste tile concrete in an aggressive environment, such as freeze and thawing, fire resistance, acid resistance, sorptivity test and abrasion test of different type of ceramic waste tile concrete.
5. The use of crushed ceramic products as fine aggregate could also be investigated.
6. Research should be carried out on the possibility of producing a machine capable of crushing ceramic wastes.

6.3 Contributions to knowledge

1. Within the limited scope of the experiments carried out in this investigation, concrete made with crushed ceramic as a partial replacement for the natural coarse aggregates can be considered a suitable alternative for normal cement concrete production.
2. The usage of these ceramic wastes in concrete as a partial substitute for coarse aggregate could be one solution in the waste removal process.

REFERENCES

- [1] Semere M., “Environmental Impacts of Coarse Aggregate Production in and around Addis Ababa”: Master of Science thesis: Addis Ababa University, p-35, 2013.
- [2] Tabsh S.W. and Abdelfatah A.S., “Influence of recycled concrete aggregates on strength properties of concrete.” *Construction and Building Materials*, 23: 1163–1167, 2009.
- [3] Rihanna N., “Partial Replacement of Cement with Marble and Ceramic waste Powders in Normal Strength Concrete”, Master of Science thesis: Addis Ababa University, 2022.
- [4] Zouren Nie, Chapter 3- Eco-Materials and Life-Cycle Assessment, Beijing University of Technology, Beijing, China, 2016, pp. 31-76, DOI:10.1016/B978-0-12-411497-5.00003-5.
- [5] Neville A.M., "Properties of Concrete", 5th edition, Pearson Education limited, 2011.
- [6] Zongjin Li., *Advanced Concrete Technology - Li* - Wiley Online Library. Published by John Wiley & Sons. Inc, Hoboken, New Jersey, USA, 2011.
- [7] Denamo A., “Handling of Concrete Making Materials in The Ethiopian Construction Industry”, Master of Science thesis: Addis Ababa University, 2005.
- [8] Abebe D., "The Need for standardization of Aggregates for Concrete Production in Ethiopian Construction Industry ", *International Conference of African Development Archives*, paper90, p-3, 2005.
- [9] Duggal S.K, "Building Materials”, third revision, new age international publishers, New Delhi, India, 2008.
- [10] Lemay L., “Life cycle assessment of concrete buildings.” A report (concrete sustainability report) prepared by NRMCA, 2011.
- [11] Hameed M., “Impact of transportation on cost, energy, and particulate emissions for recycled concrete aggregate.” Master’s Thesis, University of Florida, Florida, USA, 2009.
- [12] Marinkovic S., Radonjanin V., Malese v., and Ignjatovic I., “Comparative environmental assessment of natural and recycled aggregate concrete.” *Waste Management*, 30, 2255-2264, 2010, doi:10.1016/j.wasman.2010.04.012.
- [13] Tam V., “Economic comparison of concrete recycling: A case study approach.” *Resources, Conservation and Recycling*, 52(5): pp. 821-828, 2008.

- [14] Gashaw A. and Akililu G., “Environmental Impact and Sustainability of Aggregate Production in Ethiopia”, 2020, DOI: <http://dx.doi.org/10.5772/intechopen.90845>.
- [15] Pacheco-Torgal F. and Jalali S., “Reusing ceramic wastes in concrete”. Elsevier Ltd, construction, and building materials 24:pp832-838, 2010.
- [16] Monhun B., etal, “A Review Paper On Utilisation Of Ceramic Waste In Concrete”, International Journal of Scientific & Engineering Research , volume 7, Issue 4, April -2016 ISSN 2229-5518, 2016.
- [17] Sivaprakash, G., Saravana, K., & Lakhi J. S, “Experimental study on partial replacement of sand by ceramic waste in concrete”. Int. J. Chem, 2016.
- [18] W. Ryan, etal, “Properties of Ceramic Raw Materials”, 2nd Edition in SI I Metric Units, 1978.
- [19] Tarik M., “Behavior of Normal Strength Reinforced Concrete Structures Incorporating Slag/Ceramic Binders”: American University of Beirut, 2022.
- [20] Henock T. “ Investigation on the Appropriateness of Ceramic Waste Materials at Hawassa Ceramics Factory as Partial replacement of Conventional Aggregate in Concrete Making”, Article of IOP conference Series, 2020.
- [21] Mebratu M., “Energy saving, and fuel switching opportunities in Tabor Ceramics Products Share Company”, Master of Science thesis: Addis Ababa University, 2011.
- [22] Amin M, etal, “Effect of using mineral admixtures and ceramic wastes as coarse aggregates on properties of ultrahigh-performance concrete”, Journal of Cleaner Production, 2020.
- [23] Miguel C.S., etal, “Mechanical performance evaluation of concrete made with recycled ceramic coarse aggregates from industrial brick waste”, Construction and Building Materials 165, 2018, pp 284–294.
- [24] A. Gonzalez-Corominas, etal, “Properties of high performance concrete made with recycled fine ceramic and coarse mixed aggregates”, 2014.
- [25] Sherin Khan, etal ,“ Use Of Ceramic Tile Waste In Concrete Mix By Partial Replacement Of Coarse Aggregate: An Experimental Study”, Journal of Emerging Technologies and Innovative Research (JETIR) 2019.
- [26] Bikash Subedi ,etal ,“ Utilization of Crushed Ceramic Tile Wastes as Partial Replacement of Coarse Aggregate in Concrete” , International Journal of Engineering Research & Technology , Vol. 9 Issue 07, July-2020.

- [27] Rajat Kumar G., et al, “Optimum utilization of ceramic tile waste for enhancing concrete properties”, 2017, (<https://doi.org/10.1016/j.matpr.2021.08.011>.)
- [28] Anna Halicka, et al , “Using ceramic sanitary ware waste as concrete aggregate”, 2013, (<http://dx.doi.org/10.1016/j.conbuildmat.2013.06.063>.)
- [29] R.Johnson, et al , “Experimental study on concrete using waste ceramic as partial replacement of aggregate”,2020, (<https://doi.org/10.1016/j.matpr.2020.11.772>.)
- [30] Aswathy Mohan et al, “Use of Clay Tile Chips as Coarse Aggregate in Concrete”, IOP Conf. Ser.: Mater. Sci. Eng ,2018,
- [31] Zegardło B. et al, “Ultra-high strength concrete made with recycled aggregate from sanitary ceramic wastes - The method of production and the interfacial”, 2016, (<http://dx.doi.org/10.1016/j.conbuildmat.2016.06.112>)
- [32] Keshavarz, Z.; Mostofinejad, D., “Porcelain, and red ceramic wastes used as replacements for coarse aggregate in concrete”. Construction and Building Materials, 195: 218–230, 2019, (<https://doi.org/10.1016/j.conbuildmat.2018.11.033>.)
- [33] Zareei,S.A,etal, “ Recycled ceramic waste high strength concrete containing wollastonite particles and micro-silica” :A comprehensive study Construction and Building Materials ,2019, (<https://doi.org/10.1016/j.conbuildmat.2018.12.161>.)
- [34] Nepomuceno et al, Mechanical performance evaluation of concrete made with recycled ceramic coarse aggregates from industrial brick waste, construction and Building Materials, 2018, (<https://doi.org/10.1016/j.conbuildmat.2018.01.052>.)
- [35] Etxeberria M.,etal , The assessment of ceramic and mixed recycled aggregates for high strength and low shrinkage concretes. Materials and Structures/Materiaux et Constructions, 2018, (<https://doi.org/10.1617/s11527-018-1244-6>.)
- [36] Rashid K.,etal , “Experimental and analytical selection of sustainable recycled concrete with ceramic waste aggregate”. Construction and Building Materials, 2017, (<https://doi.org/10.1016/j.conbuildmat.2017.07.219>.)
- [37] Siddique S., “Influence of ceramic waste on the fresh properties and compressive strength of concrete”, European Journal of Environmental and Civil Engineering, 2017,(<https://doi.org/10.1080/19648189.2016.1275985>.)
- [38] Guendouz M. et al, “Properties of flow able sand concrete containing ceramic wastes”. Journal of Adhesion Science and Technology, 33(24): 1–23, 2019, (<https://doi.org/10.1080/01694243.2019.1653594>.)

- [39] Alves A., “Mechanical properties of structural concrete with fine recycled ceramic aggregates”, *Construction and Building Materials*, 64: 103–113, 2014, (<https://doi.org/10.1016/j.conbuildmat.2014.04.037>.)
- [40] Halicka A., “Using ceramic sanitary ware waste as concrete aggregate”, *Construction and Building Materials*, 2013, (<https://doi.org/10.1016/j.conbuildmat.2013.06.063>.)
- [41] Ikponmwosa E.etal, “The Effect Of Ceramic Waste As Coarse Aggregate On Strength Properties Of Concrete” , *Nigerian Journal of Technology*, Vol. 36, No. 3, July,2017, (<http://dx.doi.org/10.4314/njt.v36i3.5>.)
- [42] Abebe D. "Construction Material Laboratory Manual ", Addis Ababa University Printing Press,June 2002.
- [43] R.M. Senthamarai, etal, “Concrete with ceramic waste aggregate”, 2005 <https://doi.org/10.1016/j>.
- [44] R. Silvestre, E. Medel, A. García, J. Navas, “Using ceramic wastes from tile industry As a partial substitute of natural aggregates in hot mix asphalt binder courses”, *construct. Build. Mater.* 45 (2013) 115–122, <https://doi.org/10.1016/j>.
- [45] R.M Senthamarai., P.Devedas and D.Gobinath, “Concrete made from ceramic industry waste: Durability properties” *Constructuon Building Materterial*, 25 (5) (2011), <https://doi.org/10.1016/j.conbuildmat.2010.11.049>.
- [46] J. García, etal, “ceramic ware waste as coarse aggregate for structural concrete production”, *Environ. Technol*, 2015, <http://www.tandfonline.com/loi/tent20>.
- [47] Sudarsana Rao, .etal, “Influence of Water Absorption of the Ceramic Aggregate on Strength Properties of Ceramic Aggregate Concrete”, *International Journal of Innovative Research in Science, Engineering and Technology*, Vol.2, Nov2013.
- [48] Sekar N.,GanesanN. And Nampoothri N., “Studies of strength characteristics on utilization of waste materials as coarse aggregate in concrete” *Int. J. Eng. Sci. Technol*, (3) (7) (2011).
- [49] P.O. Awoyera, J.M. Ndambuki, J.O. Akinmusuru, D.O. Omole, “Characterization of ceramic waste aggregate concrete”, *HBRC Journal* (2016).
- [50] H. Elçi, “Utilization of crushed floor and wall tiles as aggregate in concrete production”, *J. Clean.Prod.* 112, (2016).
- [51] D.J. Anderson, S.T. Smith, F.T.K. Au, “Mechanical properties of concrete utilizing waste ceramic as coarse aggregate”, *Construct. Build. Mater.* 117 (2016).

- [52] F. Liu, J. Liu, B. Ma, J. Huang, H. Li, “Basic properties of concrete incorporating recycled ceramic aggregate and ultra-fine sand”, *J. Wuhan Univ. Technol.- Materials Sci. Ed.* 30 (2) (2015).
- [53] M. Daniyal, S. Ahmad, “Application of waste ceramic tile aggregates in concrete, *International Journal of innovative research in science, engineering and technology*, (4)(12)(2015).
- [54] E. Vejmelková, et al, “Properties of high performance concrete containing fine-ground ceramics as supplementary cementitious material”, *Cement & Concrete Composites* 34 (2012) 55–61.
- [55] A.M. Pitarch, L. Reig, A.E. Tomás, F.J. López, “Effect of tiles, bricks and ceramic sanitary-ware recycled aggregates on structural concrete properties”, *Waste and Biomass Valorization* 10 (2017).
- [56] Tavakoli D., et al, Properties of concrete produced with waste ceramic tile aggregate” *Asian Journal of Civil Engineering* ,(14)(3)(2013).
- [57] Medina C. et al, “Reuse of Sanitary Ceramic Wastes as Coarse Aggregate in eco-efficient Concretes”, *cements and concrete composites* 34(1)48:54, 2012, DOI:10.1016/j.cemconcomp.2011.08.15.
- [58] Subramani T., Suresh B., “Experimental investigation of using ceramic waste as a coarse aggregate making light weight concrete”, *International Journal of Application or Innovation in Engineering & Management* 4 (5) (2015).
- [59] Y. Tabak, M. Kara, E. Günay, S.T. Yildirim, Ş. Yilmaz, “ Ceramic tile waste as a waste management solution for concrete”, *Proceedings of the 3rd International Conference on Industrial and Hazardous Waste Management (CRETE)*, 2012.
- [60] ASTM Standards C618 “Specification of Coal ,Flyash and Raw or Calcined Natral Pozzolana for use as a Mineral Admixture in Portland cements Concrete” , ASTM International, West Conshohocken, PA, United States , (2003),
- [61] ASTM Standards C311, “Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete”, ASTM International, West Conshohocken, PA, United States, (2003).
- [62] Derrick J. Anderson et al., “Mechanical properties of concrete utilizing waste ceramic as coarse aggregate ”, *construction and building material* 117(2016) 20-28, <http://dx.doi.org/10.1016/j.conbuildmat.2016.04.153>.

APPENDIX – A1 TESTS FOR CONCRETE INGREDIENTS

A1.1: Tests for Fine aggregates

1. Silt Content

The objective of the test is to determine the silt (finer than No.200 sieve) content in a sand.

Formula:-

$$\text{Silt content} = \frac{A}{B} * 100 \quad \text{Where: A: amount of silt deposited above the sand} = 6 \text{ ml}$$

$$\text{B: amount of clean sand} = 294 \text{ml}$$

Calculation:-

$$\text{Before washing: - Silt content (\%)} = \frac{19.75}{280.25} = 7.05 \% > 6 \% \text{ is not ok!}$$

$$\text{After washing: - Silt content (\%)} = \frac{6}{294} * 100 = 2.04 \% < 6 \% \text{ is not ok!}$$

According to the Ethiopian standard, if the sand contains over 6% silt, it shall not be used for construction. The sand used for this research has silt content of less than 6%, therefore it is suitable for construction.

2. Sieve analysis

The objective of the test is to determine the particle size distribution of fine aggregate. Table 1 shows the grading requirement of sand and Table 2 below shows the particle size distribution as per ASTM standard. As it is depicted in, the figure 1 below the sample sand satisfies the graduation requirement of ASTM standard.

Table 1: Grading requirement for fine aggregate.

Percentage passing through test sieves having square openings						
9.5mm	4.75 mm	2.36 mm	1.18 mm	600µm	300µm	150 µm
100	95-100	80-100	50-85	25-60	10-30	2-10

Table.2: Sieve analysis test result of fine aggregate

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve & Retained (gm)	Wt. of Retained (gm)	Percentage retained (%)	Cumul. Coarser (%)	Cumul. Passing (%)
9.5			0	0		100
4.75	431.3	439.6	8.3	1.66	1.66	98.3
2.36	387.2	439.0	51.8	10.36	12.02	88.0
1.18	373.0	485.1	112.1	22.42	34.44	65.6
600µm	324.8	457.7	132.9	26.58	61.02	39
300µm	302.8	428.7	125.9	25.18	86.20	13.8
150µm	283.1	310.0	26.9	5.38	91.51	8.4
Pan	240.4	282.50	42.1	8.42	100.0	
Total			500		280	

$$\text{Fineness modulus (FM)} = \frac{\sum \text{Cummulative Coarser}}{100} * 100 = 280/100 = 2.80$$

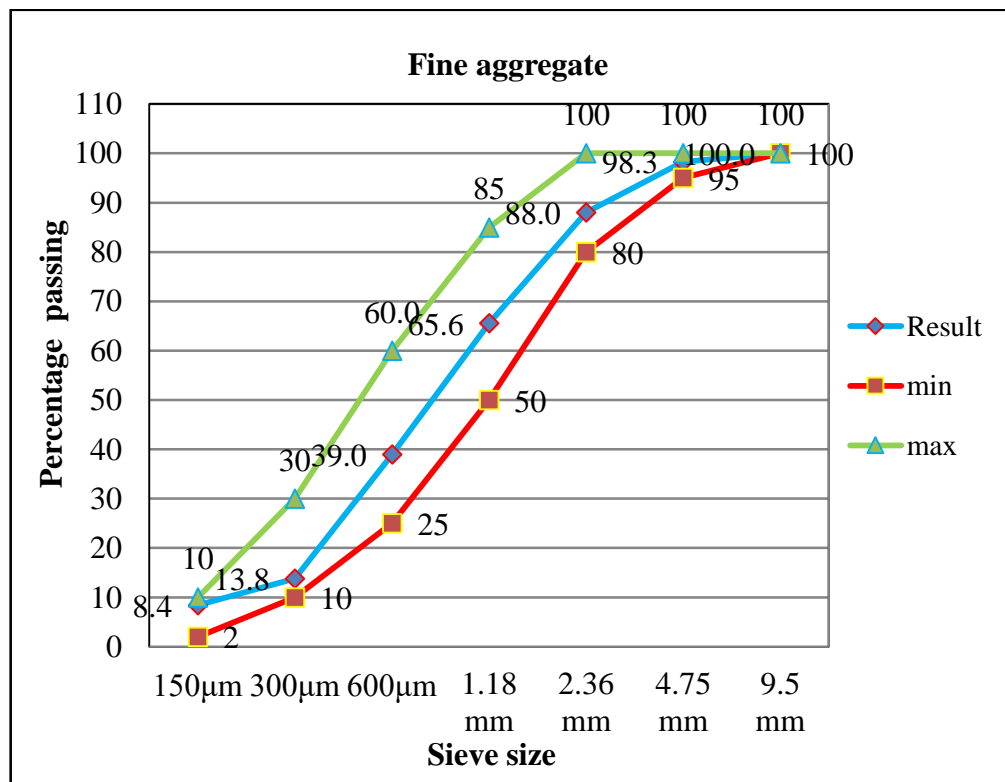


Figure 1 Graphical representation of sieve analysis of fine aggregate

3. Specific gravity and absorption capacity

The objective of this test is to determine bulk and apparent specific gravity, and absorption of fine aggregate.

Formula: -

$$C = 0.9976 V_A + 500 + W$$

$$B = 0.9976 V + W$$

$$\text{Bulk specific gravity} = \frac{A}{B + 500 - C}$$

$$\text{Bulk specific Gravity (SSD basis)} = \frac{500}{B + 500 - C}$$

$$\text{Apparent Specific Gravity} = \frac{A}{B + A - C}$$

$$\text{Absorption Capacity (\%)} = \frac{500 - A}{A} * 100$$

Where: -

C: weight of pycnometer filled with sample plus water, [g]

V_A: volume of water added to pycnometer, [cm³]

V: Volume of flask, [cm³]

W: weight of the pycnometer empty, [g]

A: weight of oven-dry sample in air, [g]

B: weight of pycnometer filled with water, [g] and

C: weight of pycnometer with sample and water to calibration, [g]

Test result: -

Weight of sample = 500 gm

$$W = 320 \text{ gm}$$

$$V = 976.5 \text{ cm}^3$$

$$VA = 768 \text{ cm}^3$$

$$A = 474 \text{ gm}$$

Calculation: -

$$C = 0.9976 * 768 + 500 + 320 = 1586.16 \text{ gm}$$

$$B = 0.9976 * 976.5 + 320 = 1294.16 \text{ gm}$$

$$\text{Bulk specific gravity} = \frac{A}{B + 500 - C} = \frac{474}{1294.16 + 500 - 1586.16} = 2.28$$

$$\text{Bulk specific Gravity (SSD basis)} = \frac{500}{B + 500 - C} = \frac{500}{1294.16 + 500 - 1586.16} = 2.40$$

$$\text{Apparent Specific Gravity} = \frac{A}{B + A - C} = \frac{474}{1294.16 + 474 - 1586.16} = 2.60$$

$$\text{Absorption Capacity (\%)} = \frac{500 - A}{A} \times 100 = \frac{500 - 474}{474} \times 100 = 5.48 \%$$

Note: When computing the quantities for concrete mixes using ACI mix design the specific gravity of saturated surface dry (SSD) aggregate value is used

4. Moisture content

The objective of this test is to determine the moisture content of fine aggregate.

Formula: -

$$W(\%) = \frac{A - B}{B} \times 100$$

Where: -

W: Moisture content (%)

A: weight of original sample [gm] and

B: weight of oven dry sample, [gm]

Test result: -

A= 500 gm.

B =462.96gm

Calculation: -

$$W(\%) = \frac{(500 - 462.96)}{462.96} * 100 = 8\%$$

5. Unit weight of fine aggregates (sand)

The weight of a specific volume of graded aggregate is known as a unit weight. Therefore, it is a density measurement also referred to as bulk density. It is determined by filling a bucket with a predetermined volume and weighing it using rodding procedure.

The test results:

Weight of measuring apparatus = 4842 gm

Weight of sample and measuring apparatus =25702 gm

Formula: -

$$\text{Volume of measuring apparatus} = \frac{\pi D^2 h}{4}$$

Where:-

D: inside diameter of measuring apparatus =253mm

h: height of measuring apparatus = 275mm

$\pi = 3.14$

Calculation: -

$$\text{Volume of measuring apparatus} = \frac{3.14 * 0.253^2 * 0.275}{4} = 0.014 \text{ m}^3$$

$$\text{Unit weight of coarse aggregate} = \frac{25.702 - 4.842}{0.014} = 1490 \text{ kg/ m}^3$$

A1.2: Tests for Coarse Aggregates

1. Sieve analysis

A sieve analysis is an analytical technique used to determine the particle size distribution of a granular material with macroscopic granular sizes. The sieve analysis technique involves several layers of sieves with different grades of sieve opening sizes. The finest sized sieve lies on the bottom of the stack with each layered sieve stacked above in order of increasing sieve size.

The requirement from ASTM standard for grading coarse aggregate regarding of percentage of passing through each sieves are presented in Table 3 as depicted below.

Table 3 Grading requirement for coarse aggregate

Nominal size of aggregate ,mm	Percentage passing through test sieves having square openings						
	75mm	63mm	37.5mm	19mm	13.2mm	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

The test results:

Table 4: Sieve analysis test result of crushed ceramic aggregates

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve & Retained (gm)	Wt. of Retained (gm)	Percentage retained (%)	Cumul. Coarser (%)	Cumul. Passing (%)	Standard Limit (%)
19			0	0	0	100	100
12.5	1158	1258	100	5	5	95	90-100
9.5	1163	1962	799.99	40	45	55	40-85
4.75	1260	2359.99	1099.99	55	100	0	0-10
			1999.98				

Table 4 above displays particle size distribution of coarse aggregate is within the allowable range. The cumulative percent passing of each sieve number fulfils with ASTM requirements as it is shown graphically in Figure 2.

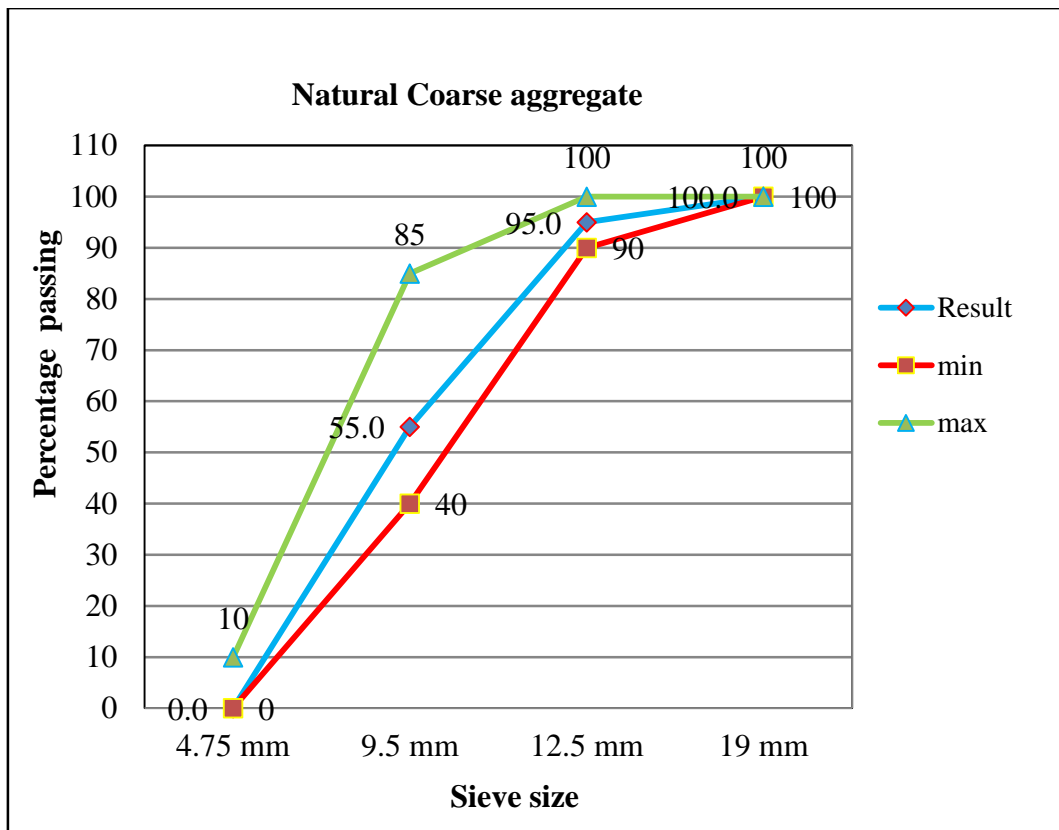


Figure 2. Graphical representation of sieve analysis of coarse aggregate

2. Specific gravity and water absorption

Specific gravity, also called relative density, ratio of the density of a substance to that of a standard substance. The usual standard of comparison for solids and liquids is water. An approximate aggregate sample of 5kg was required, by using quartering from the sample. All aggregates passing No. 4(4.75mm) sieve were rejected.

Formula: -

$$\text{Bulk specific gravity} = \frac{A}{B - C}$$

$$\text{Bulk specific Gravity (SSD basis)} = \frac{B}{B - C}$$

$$\text{Apparent Specific Gravity} = \frac{A}{A - C}$$

$$\text{Absorption Capacity (\%)} = \frac{B - A}{A} * 100$$

Where: -

A: weight of oven-dry sample in air, [g]

B: weight of saturated-surface-dry sample in air, [g] and

C: weight of saturated sample in water, [g]

Calculation: -

$$\text{Bulk specific gravity} = \frac{4958}{5003 - 3138} = 2.66$$

$$\text{Bulk specific Gravity (SSD basis)} = \frac{5003}{5003 - 3138} = 2.68$$

$$\text{Apparent Specific Gravity} = \frac{4958}{4958 - 3138} = 2.72$$

$$\text{Absorption Capacity (\%)} = \frac{5003 - 4958}{4958} * 100 = 0.91\%$$

3. Moisture content

The objective of this test is to determine the moisture content of coarse aggregate.

Formula: -

$$w = \frac{A - B}{B} * 100$$

Where: -

W: Moisture content (%)

A: weight of original sample [gm] and

B: weight of oven dry sample, [gm]

The test results:

A = 2000gm

B = 1915.6gm

Calculation: -

$$w = \frac{2000 - 1915.6}{1915.6} * 100 = 4.4\%$$

4. Unit weight of aggregates

The weight of a specific volume of graded aggregate is known as a unit weight. Therefore, it is a density measurement also referred to as bulk density. It is determined by filling a bucket with a predetermined volume and weighing it using rodding procedure. This method is applicable to aggregates of 40mm maximum size. For this project, an oven-dry aggregate sample is used.

The test results:

Weight of measuring apparatus = 4842 gm

Weight of sample and measuring apparatus = 28110 gm

Formula: -

$$\text{Volume of measuring apparatus} = \frac{\pi D^2 h}{4}$$

Where:-

D: inside diameter of measuring apparatus = 253mm

h: height of measuring apparatus = 275mm

$\pi = 3.14$

Calculation: -

$$\text{Volume of measuring apparatus} = \frac{3.14 * 0.253^2 * 0.275}{4} = 0.014 \text{ m}^3$$

$$\text{Unit weight of coarse aggregate} = \frac{28.11 - 4.842}{0.014} = 1662 \text{ kg/ m}^3$$

A1.3: Tests for Ceramic Coarse Aggregates

1. Sieve analysis

A sieve analysis is an analytical technique used to determine the particle size distribution of a granular material with macroscopic granular sizes. The sieve analysis technique involves several layers of sieves with different grades of sieve opening sizes. The finest sized sieve lies on the bottom of the stack with each layered sieve stacked above in order of increasing sieve size.

The requirement from ASTM standard for grading coarse aggregate regarding of percentage of passing through each sieves are presented in Table 5 as depicted below.

Table 5. Grading requirement for coarse aggregate.

Nominal size of aggregate, mm	Percentage passing through test sieves having square openings						
	75mm	63mm	37.5mm	19mm	13.2mm	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 6. Sieve analysis test result of crushed ceramic aggregates

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve & Retained (gm)	Wt. of Retained (gm)	Percentage retained (%)	Cumul. Coarser (%)	Cumul. Passing (%)	Standard Limit (%)
19			0	0	0	100	100
12.5	1159	1257	97	4.9	4.9	95.1	90-100
9.5	1162	1963	801	40.07	44.97	55	40-85
4.75	1259	2359	1100	55.03	100	0	0-10
			1999.88				

Table 6 above shows that sieve analysis test result of coarse ceramic aggregate is within the standard limit. The cumulative percent passing of each sieve number complies with ASTM standard as shown in Figure 3 below.

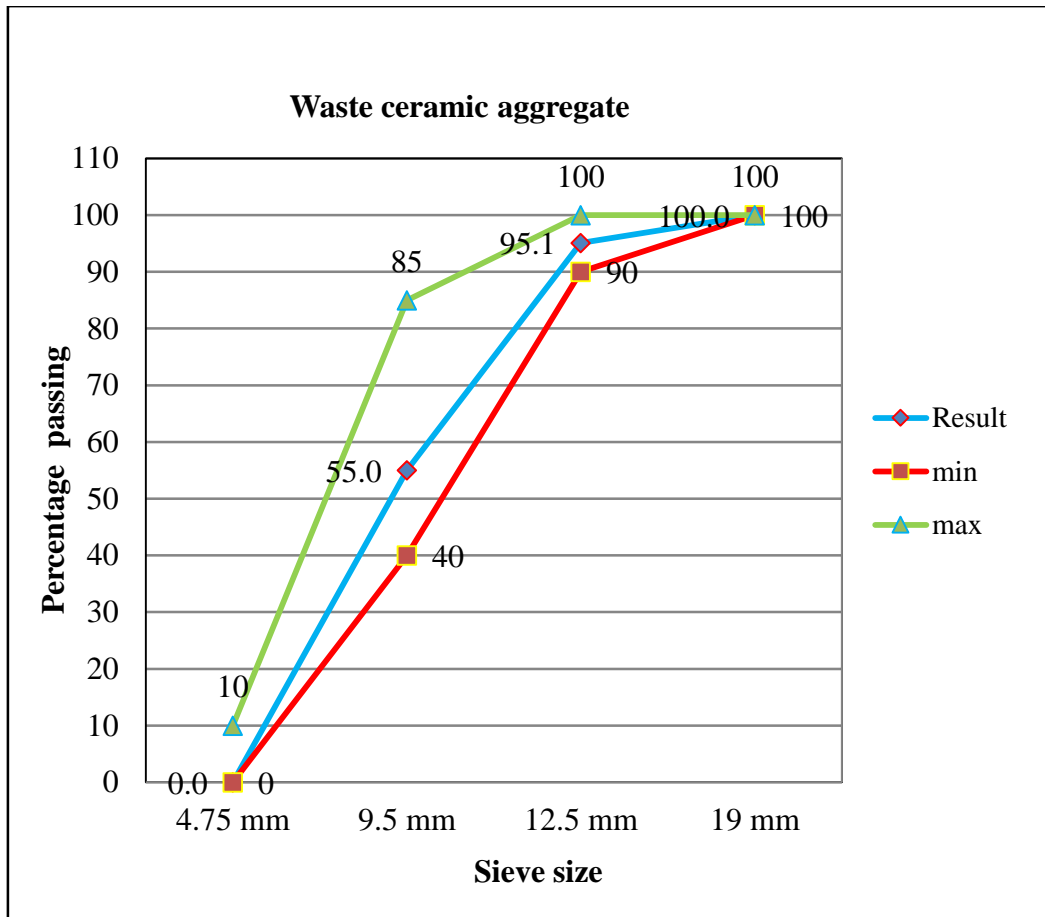


Figure 3. Graphical representation of sieve analysis of coarse aggregate

2. Specific gravity and water absorption

The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. An approximate aggregate sample of 5kg was required, by using quartering from the sample. All aggregates passing No. 4(4.75mm) sieve were rejected.

Formula: -

$$\text{Bulk specific gravity} = \frac{A}{B - C}$$

$$\text{Bulk specific Gravity (SSD basis)} = \frac{B}{B - C}$$

$$\text{Apparent Specific Gravity} = \frac{A}{A - C}$$

$$\text{Absorption Capacity (\%)} = \frac{B - A}{A} * 100$$

Where: -

A: weight of oven-dry sample in air, [gm]

B: weight of saturated-surface-dry sample in air, [gm] and

C: weight of saturated sample in water, [gm]

The test results:

A=4946 gm

B=5010gm

C=2878gm

Calculation: -

$$\text{Bulk specific gravity} = \frac{A}{B - C} = \frac{4946}{5010 - 2878} = 2.32$$

$$\text{Bulk specific Gravity (SSD basis)} = \frac{B}{B - C} = \frac{5010}{5010 - 2878} = 2.35$$

$$\text{Apparent Specific Gravity} = \frac{A}{A - C} = \frac{4946}{4946 - 2878} = 2.39$$

$$\text{Absorption Capacity (\%)} = \frac{B - A}{A} * 100 = \frac{5010 - 4946}{4946} * 100 = 4.5\%$$

3. Moisture content

The objective of this test is to determine the moisture content of coarse aggregate.

Formula: -

$$w = \frac{A - B}{B} * 100$$

Where: -

W: Moisture content (%)

A: weight of original sample [g] and

B: weight of oven dry sample, [g]

The test results:

A=2000gm

B=1993.62gm

Calculation: -

$$w = \frac{A-B}{B} * 100 = \frac{(2000-1993.62)}{1993.62} * 100 = 0.32\%$$

4. Unit weight of crushed ceramic aggregates

The weight of a specific volume of graded aggregate is known as a unit weight. Therefore, it is a density measurement also referred to as bulk density. It is determined by filling a bucket with a predetermined volume and weighing it using rodding procedure. This method is applicable to aggregates of 40mm maximum size. For this project, an oven-dry aggregate sample is used.

The test results:-

Weight of measuring apparatus = 4842 gm

Weight of sample and measuring apparatus = 21838 gm

Formula: -

$$\text{Volume of measuring apparatus} = \frac{\pi * D^2 * h}{4}$$

Where:-

D: inside diameter of measuring apparatus = 253mm

h: height of measuring apparatus = 275mm

$\pi = 3.14$

Calculation: -

$$\text{Volume of measuring apparatus} = \frac{3.14 * 0.253^2 * 0.275}{4} = 0.014 \text{m}^3$$

$$\text{Unit weight of coarse aggregate} = \frac{21.838 - 4.842}{0.014} = 1214 \text{ kg/ m}^3$$

APPENDIX – B2 MIX DESIGN (AMERICAN CONCRETE INSTITUTE)

B2.1: C 20 Concrete Mix Design

The quantity of water, cement, and fine aggregate and coarse aggregate was proportioned as per ACI 211.1 “ Proportions for normal, heavyweight, and mass concrete. ”

Replacement of coarse aggregate with 0 % crushed ceramic tiles.

Grade of Concrete- C-20

Properties of cement:-

Specific gravity: 3.15

Cement: Dangote OPC 42.5N

The specified 28day 150mm cubic specimen compressive strength (f'_c) is 20MPa, the equivalent cylindrical (150 mm dia. \times 300 mm) compressive strength was calculated based on the conversion factor given in the researches related to ACI founds a conversion factor of 1.15 to 1.25 to convert 150x150x150mm cube strength to cylindrical strength. Whereas, EBCS 2 table 2.2 or Euro Code EN-206 recommends a conversion factor of 1.25 in order to convert 150mm cube strength to cylindrical 300x150mm.

Therefore, the required compressive strength was calculated as:

$$f'_c (\text{cylindrical}) = f'_c (\text{cube}) / 1.25 = 20/1.25 = 16 \text{ MPa (which is less than 21 MPa)}$$

$$f'_{cr} = f'_c + 7 = 16 + 7 = 23 \text{ Mpa}$$

Where: f'_c – is the specified compressive strength &

f'_{cr} – is the required compressive strength

Mix Design Procedure

Step 1 - Choosing slump height

The slump being fixed as 40mm, according to ACI table A1.5.3.1 for pavements and slabs,

Step 2 - Choosing nominal maximum size of aggregate

The aggregate to be used has a nominal maximum size of 12.5 mm.

Step 3 – Computing quantity of mixing water

According to ACI 211.1 on Table A1.5.3.3, for nominal maximum size of 12.5mm coarse aggregate and for 25-50 mm slump, the estimated water content is $199 \text{ kg} / \text{m}^3$.

Step 4 –water to cement ratio (w/c)

From ACI 211.1 on Table A1.5.3.4 (a): by interpolation the water to cement ratio is 0.64.

Step 5 – Quantity of cement

For 23 Mpa concrete the cement content is $(199 \text{ kg} / \text{m}^3) / 0.64 = 311 \text{ kg} / \text{m}^3$

Step 6 – Quantity of coarse aggregate

From ACI 211.1 on Table A1.5.3.6, for nominal maximum size of 12.5 mm coarse aggregate and fineness modulus of sand of 2.80, the volume of dry-rodded coarse aggregate per a unit volume of concrete equals to 0.55 m^3 .

Therefore, the weight of coarse aggregate = $0.55 \text{ m}^3 * 1662 \text{ kg} / \text{m}^3 = 914 \text{ kg}$

Step 7 – Quantity of sand

Vol. of water = $199 / (1*1000) = 0.199 \text{ m}^3$

Vol. of Cement = $311 / (3.15*1000) = 0.099 \text{ m}^3$

Vol. of coarse aggregate = $914 / (2.68 *1000) = 0.311 \text{ m}^3$

Vol. of entrapped air = $0.025 * 1 = 0.025 \text{ m}^3$ (From ACI 211.1, Table A1.5.3.3)

Total Vol. = $(0.199 \text{ m}^3 + 0.099 \text{ m}^3 + 0.311 \text{ m}^3 + 0.025 \text{ m}^3) = 0.634 \text{ m}^3$

Therefore, the volume of sand (fine aggregate) = $1 \text{ m}^3 - 0.634 \text{ m}^3 = 0.366 \text{ m}^3$ and

The mass of fine aggregate is = $(0.366 * 2.40 * 1000) = 878 \text{ kg}$

Weight of ingredients for 1 m^3 of fresh concrete:

Materials	Quantity (Kg)
Water (net mixing)	199
Cement	311
Fine aggregate	878
Coarse aggregate	914
Crushed ceramic tiles	0
Total	2302

Step 8 – Adjustment for moisture aggregate

But the moisture content is worth of consideration, the masses of the aggregates shall be adjusted. Thus, due to the moisture contents determined in the lab test,

$$\text{Coarse aggregate (wet)} = 914 + (914 * 4.4\%) = 954 \text{ kg}$$

$$\text{Fine aggregate (wet)} = 878 + (878 * 8\%) = 948 \text{ kg}$$

Then, the surface water contained in the wet aggregate excluding the absorbed water should be reduced from the added water adjustment. Thus, the estimated requirement for added water becomes:-

$$\text{Added water} = \text{mixing water} - (\text{moisture} - \text{absorbed water})$$

$$\text{Added water} = 199 - [(914 * (4.4\% - 0.91\%)) + (878 * (8\% - 5.48\%))] = 145 \text{ kg}$$

Therefore the estimated batch masses per cubic meter of concrete after adjustment for moisture and absorption are:

Materials	Quantity (Kg)
Water	145
Cement	311
Fine aggregate (wet)	948
Coarse aggregate (wet)	954
Crushed ceramic tiles	0
Total	2358

Step 9 – Trial mix

For the laboratory trial batch, it is found convenient to scale the masses down to produce 0.02 m³ of concrete as below:-

Materials	Quantity (Kg)
Water	2.90
Cement	6.22
Fine aggregate (wet)	18.96
Coarse aggregate (wet)	19.08
Crushed ceramic tiles	0
Total	47.16

Step 10 – Trial batch adjustment

1st adjustment for Slump of the trial batch,

If there is need of either adding or reducing of mixing water, the quantity of the ingredients can be re-estimated by adding or reducing kg of water for any unit of slump to be increased or decreased. For any 10 mm slump to be increased or decreased, add or reduce 2kg water per m³ of concrete; (ACI 211 Section A1.5.3.9.1).

The amount actually used in the effort to obtain the desired slump of 40 mm is 2.80 kg. The batch as mixed, therefore, consists of:-

Materials	Quantity (Kg)
Water	2.80
Cement	6.22
Fine aggregate	18.96
Coarse aggregate	19.08
Crushed ceramic tiles	0
Total	47.06

The concrete has a measured slump of 40 mm and unit mass of 2253 kg /m³

Step 10.1 – Yield of trial mix

Mixing water content:-

Materials	Quantity (Kg)
Water	2.80
From Fine aggregate	0.44
From Coarse aggregate	0.64
Total	3.88

The mixing water required for a cubic meter of concrete with the slump of 40 mm slump as the trial batch is 194 kg:-

Step 10.2 – Cement quantity adjustment

Since the water content has changed the amount of cement is computed to be 303 kg.

Step 10.3 – Quantities of ingredients after adjustment

Materials	Quantity per 1 m ³	
	In terms of dry mass of aggregates (Kg)	In terms of wet mass of aggregates (Kg)
Mixing water	194	194
Cement	303	303
Fine aggregate	878	948
Coarse aggregate	949	954
Total	2324	2399

Ingredients	Quantity per 0.02 m ³	
	In terms of dry mass of aggregates (Kg).	In terms of wet mass of aggregates (Kg).
Mixing water	3.88	3.88
Cement	6.06	6.06
Fine aggregate	17.56	18.96
Coarse aggregate	18.98	19.08
Total	46.48	47.98

B2.2: C25 Concrete Mix Design

The quantity of water, cement, and fine aggregate and coarse aggregate was proportioned as per ACI 211.1 “ Proportions for normal, heavyweight, and mass concrete. ”

Replacement of coarse aggregate with 0 % crushed ceramic tiles.

Grade of Concrete- C-25

Properties of cement:-

Specific gravity: 3.15

Cement: Dangote OPC 42.5N

The specified 28day 150mm cubic specimen compressive strength (f'_c) is 25MPa, the equivalent cylindrical (150 mm dia. \times 300 mm) compressive strength was calculated based on the conversion factor given in the researches related to ACI finds a conversion factor of 1.15 to 1.25 to convert 150x150x150mm cube strength to cylindrical strength. Whereas, EBCS 2 table 2.2 or Euro Code EN-206 recommends a conversion factor of 1.25 in order to convert 150mm cube strength to cylindrical 300x150mm.

Therefore, the required compressive strength was calculated as:

$$f'_c \text{ (cylindrical)} = f'_c \text{ (cube)} / 1.25 = 25 / 1.25 = 20 \text{ MPa (which is less than 21 MPa)}$$

$$f'_{cr} = f'_c + 7 = 20 + 7 = 27 \text{ Mpa}$$

Where: f'_c – is the specified compressive strength &

f'_{cr} – is the required compressive strength

Mix Design Procedure

Step 1 - Choosing slump height

The slump being fixed as 40mm, according to ACI table A1.5.3.1 for pavements and slabs,

Step 2 - Choosing nominal maximum size of aggregate

The aggregate to be used has a nominal maximum size of 12.5 mm.

Step 3 – Computing quantity of mixing water

According to ACI 211.1 on Table A1.5.3.3, for nominal maximum size of 12.5mm coarse aggregate and for 25-50 mm slump, the estimated water content is $199 \text{ kg} / \text{m}^3$.

Step 4 – water to cement ratio (w/c)

From ACI 211.1 on Table A1.5.3.4 (a): by interpolation the water to cement ratio is 0.58.

Step 5 – Quantity of cement

For 27 Mpa concrete the cement content is $(199 \text{ kg} / \text{m}^3) / 0.58 = 343 \text{ kg} / \text{m}^3$

Step 6 – Quantity of coarse aggregate

From ACI 211.1 on Table A1.5.3.6, for nominal maximum size of 12.5 mm coarse aggregate and fineness modulus of sand of 2.80, the volume of dry- rodded coarse aggregate per a unit volume of concrete equals to 0.55 m^3 .

Therefore, the weight of coarse aggregate = $0.55 \text{ m}^3 * 1662 \text{ kg} / \text{m}^3 = 914 \text{ kg}$

Step 7 – Quantity of sand

Vol. of water = $199 / (1*1000) = 0.199 \text{ m}^3$

Vol. of Cement = $343 / (3.15*1000) = 0.109 \text{ m}^3$

Vol. of coarse aggregate = $914 / (2.68 *1000) = 0.341 \text{ m}^3$

Vol. of entrapped air = $0.025 * 1 = 0.025 \text{ m}^3$ (From ACI 211.1, Table A1.5.3.3)

Total Vol. = $(0.199 \text{ m}^3 + 0.109 \text{ m}^3 + 0.341 \text{ m}^3 + 0.025 \text{ m}^3) = 0.674 \text{ m}^3$

Therefore, the volume of sand (fine aggregate) = $1 \text{ m}^3 - 0.674 \text{ m}^3 = 0.326 \text{ m}^3$ and

The mass of fine aggregate is = $(0.326 * 2.40 * 1000) = 782 \text{ kg}$

Weight of ingredients for 1 m^3 of fresh concrete:

Materials	Quantity (Kg)
Water (net mixing)	199
Cement	343
Fine aggregate	782
Coarse aggregate	914
Crushed ceramic tiles	0
Total	2238

Step 8 – Adjustment for moisture aggregate

But the moisture content is worth of consideration, the masses of the aggregates shall be adjusted. Thus, due to the moisture contents determined in the lab test,

$$\text{Coarse aggregate (wet)} = 914 + (914 * 4.4\%) = 954 \text{ kg}$$

$$\text{Fine aggregate (wet)} = 782 + (782 * 8\%) = 844 \text{ kg}$$

Then, the surface water contained in the wet aggregate excluding the absorbed water should be reduced from the added water adjustment. Thus, the estimated requirement for added water becomes:-

$$\text{Added water} = \text{mixing water} - (\text{moisture} - \text{absorbed water})$$

$$\text{Added water} = 199 - [(914 * (4.4\% - 0.91\%)) + (782 * (8.0\% - 5.48\%))] = 147 \text{ kg}$$

Therefore the estimated batch masses per cubic meter of concrete after adjustment for moisture and absorption are:

Materials	Quantity (Kg)
Water (to be added)	147
Cement	343
Fine aggregate (wet)	844
Coarse aggregate (wet)	954
Crushed ceramic tiles	0
Total	2288

Step 9 – Trial mix

For the laboratory trial batch, it is found convenient to scale the masses down to produce 0.02 m³ of concrete as below:-

Materials	Quantity (Kg)
Water (added)	2.94
Cement	6.86
Fine aggregate (wet)	16.88
Coarse aggregate (wet)	19.08
Crushed ceramic tiles	0
Total	45.76

Step 10 – Trial batch adjustment

1st adjustment for Slump of the trial batch,

If there is need of either adding or reducing of mixing water, the quantity of the ingredients can be re-estimated by adding or reducing kg of water for any unit of slump to be increased or decreased. For any 10 mm slump to be increased or decreased, add or reduce 2kg water per m³ of concrete; (ACI 211 Section A1.5.3.9.1).

The amount actually used in the effort to obtain the desired slump of 40 mm is 2.60 kg. The batch as mixed, therefore, consists of:-

Materials	Quantity (Kg)
Water (to be added)	3.89
Cement	6.86
Fine aggregate	16.88
Coarse aggregate	19.08
Crushed ceramic tiles	0
Total	46.71

The concrete has a measured slump of 40 mm and unit mass of 2335 kg /m³

Step 10.1 – Yield of trial mix

Mixing water content:-

Materials	Quantity (Kg)
Water	3.09
From Fine aggregate	0.39
From Coarse aggregate	0.64
Total	4.12

The mixing water required for a cubic meter of concrete with the slump of 40 mm slump as the trial batch is 206 kg:-

Step 10.2 – Cement quantity adjustment

Since the water content has changed the amount of cement is computed to be 355 kg.

Step 10.3 – Quantities of ingredients after adjustment

Materials	Quantity per 1 m ³	
	In terms of dry mass of aggregates (Kg)	In terms of wet mass of aggregates (Kg)
Mixing water	206	206
Cement	355	355
Fine aggregate	782	844
Coarse aggregate	914	954
Total	2257	2359

Materials	Quantity per 0.02 m ³	
	In terms of dry mass of aggregates (Kg)	In terms of wet mass of aggregates (Kg)
Mixing water	4.12	4.12
Cement	7.10	7.10
Fine aggregate	15.64	16.88
Coarse aggregate	18.28	19.08
Total	45.14	47.18

APPENDIX - C3 COMPRESSIVE STRENGTH TEST RESULT

C3.1: C20 Compression Strength for zero percent ceramic substitution.

Strength C20
 Mix Designation C20C00
 Ceramic substitution 0%

No	Age (days)	Ceramic waste (%)	Size of specimen (cm)			Wt. (gm)	Vol. (cm ³)	Failure Load (Kn)	Comp. Strength (Mpa)	Unit Wt. (gm/cm ³)
			L	W	H					
1	7	0	15	15	15.3	7987	3442.5	330.75	14.70	2.32
2		0	15	15	15.1	7950	3397.5	337.10	14.98	2.34
3		0	15	15	15.2	8037	3420.0	333.00	14.80	2.35
Mean									14.83	2.34
1	14	0	15	15	15.1	7882	3397.5	382.73	17.01	2.32
2		0	15	15	15.2	7934	3420.0	384.98	17.11	2.32
3		0	15	15	15.3	7952	3442.5	382.95	17.02	2.31
Mean									17.05	2.32
1	28	0	15	15	15.2	7832	3420.0	632.48	28.11	2.29
2		0	15	15	15.1	7814	3397.5	636.98	28.31	2.30
3		0	15	15	15.3	7918	3442.5	628.20	27.92	2.30
Mean									28.11	2.30

C3.2: C20 Compression Strength for ten percent ceramic substitution.

Strength C20
 Mix Designation C20C10
 Ceramic substitution 10%

No	Age (days)	Ceramic waste (%)	Size of specimen (cm)			Wt. (gm)	Vol. (cm ³)	Failure Load (Kn)	Comp. Strength (Mpa)	Unit Wt. (gm/cm ³)
			L	W	H					
1	7	10	15	15	15.2	7866	3442.0	342.00	15.20	2.30
2		10	15	15	15.1	7882	3397.5	347.40	15.44	2.32
3		10	15	15	15.2	7832	3420.0	337.73	15.01	2.29
Mean									15.22	2.30
1	14	10	15	15	15.2	7729	3420.0	414.00	18.40	2.26
2		10	15	15	15.1	7780	3397.5	392.40	17.44	2.29
3		10	15	15	15.3	7952	3442.5	402.08	17.87	2.31
Mean									17.90	2.29
1	28	10	15	15	15.2	7763	3420.0	654.98	29.11	2.27
2		10	15	15	15.1	7746	3397.5	652.05	28.98	2.28
3		10	15	15	15.1	7780	3397.5	649.35	28.86	2.29
Mean									28.98	2.28

C3.3: C20 Compression Strength for twenty percent ceramic substitution.

Strength C20
 Mix Designation C20C20
 Ceramic substitution 20%

No	Age (days)	Ceramic waste (%)	Size of specimen (cm)			Wt. (gm)	Vol. (cm ³)	Failure Load (Kn)	Comp. Strength (Mpa)	Unit Wt. (gm/cm ³)
			L	W	H					
1	7	10	15	15	15.3	7849	3442.5	374.85	16.66	2.28
2		10	15	15	15.1	7780	3397.5	359.33	15.97	2.29
3		10	15	15	15.1	7848	3397.5	401.85	17.86	2.31
Mean									16.83	2.29
1	14	10	15	15	15.2	7695	3420.0	445.95	19.82	2.25
2		10	15	15	15.3	7746	3442.5	425.70	18.92	2.25
3		10	15	15	15.3	7814	3442.5	404.10	17.96	2.27
Mean									18.90	2.26
1	28	10	15	15	15.1	7610	3397.5	678.38	30.15	2.24
2		10	15	15	15.1	7712	3397.5	663.53	29.49	2.27
3		10	15	15	15.2	7695	3420.0	652.28	28.99	2.25
Mean									29.54	2.25

C3.4: C20 Compression Strength for thirty percent ceramic substitution.

Strength C20
 Mix Designation C20C30
 Ceramic substitution 30%

No	Age (days)	Ceramic waste (%)	Size of specimen (cm)			Wt. (gm)	Vol. (cm ³)	Failure Load (Kn)	Comp. Strength (Mpa)	Unit Wt. (gm/cm ³)
			L	W	H					
1	7	10	15	15	15.1	7644	3397.5	337.30	14.99	2.25
2		10	15	15	15.0	7661	3375.0	337.73	15.01	2.27
3		10	15	15	15.1	7678	3397.5	337.05	14.98	2.26
Mean									14.99	2.26
1	14	10	15	15	15.2	7627	3420.0	396.90	17.64	2.23
2		10	15	15	15.2	7729	3420.0	394.88	17.55	2.26
3		10	15	15	15.1	7610	3397.5	395.78	17.59	2.24
Mean									17.59	2.24
1	28	10	15	15	15.2	7661	3420.0	647.33	28.77	2.24
2		10	15	15	15.1	7508	3397.5	649.35	28.86	2.21
3		10	15	15	15.1	7576	3397.5	643.28	28.59	2.23
Mean									28.59	2.23

C3.5: C25 Compression Strength for zero percent ceramic substitution.

Strength C25
 Mix Designation C25C30
 Ceramic substitution 0%

No	Age (days)	Ceramic waste (%)	Size of specimen (cm)			Wt. (gm)	Vol. (cm ³)	Failure Load (Kn)	Comp. Strength (Mpa)	Unit Wt. (gm/cm ³)
			L	W	H					
1	7	0	15	15	15	7882.2	3397.5	470.03	20.89	2.36
2		0	15	15	15	8105.4	3420.0	461.48	20.51	2.37
3		0	15	15	15	8018.1	3397.5	450.00	20.00	2.36
Mean									20.47	2.36
1	14	0	15	15	15	7729.2	3420.0	648.90	28.84	2.26
2		0	15	15	15	8403.1	3442.5	617.85	27.46	2.44
3		0	15	15	15	8018.1	3397.5	606.38	26.95	2.36
Mean									27.75	2.35
1	28	0	15	15	15	7952.2	3442.5	765.23	34.01	2.31
2		0	15	15	15	7968.6	3420.0	728.78	32.39	2.33
3		0	15	15	15	7934.4	3420.0	746.78	33.19	2.32
Mean									33.20	2.32

C3.6: C25 Compression Strength for ten percent ceramic substitution.

Strength C25
 Mix Designation C25C10
 Ceramic substitution 10%

No	Age (days)	Ceramic waste (%)	Size of specimen (cm)			Wt. (gm)	Vol. (cm ³)	Failure Load (Kn)	Comp. Strength (Mpa)	Unit Wt. (gm/m ³)
			L	W	H					
1	7	10	15	15	15	8002.8	3420.0	560.48	24.91	2.34
2		10	15	15	15	7882.2	3397.5	540.23	24.01	2.32
3		10	15	15	15	7916.2	3397.5	546.98	24.31	2.33
Mean									24.41	2.33
1	14	10	15	15	15	7934.4	3420.0	699.98	31.11	2.32
2		10	15	15	15	7968.2	3420.0	702.00	31.20	2.33
3		10	15	15	15	7848.2	3397.5	699.98	31.11	2.31
Mean									31.14	2.32
1	28	10	15	15	15	7814.2	3397.5	816.08	36.27	2.30
2		10	15	15	15	7900.2	3420.0	803.70	35.72	2.31
3		10	15	15	15	7780.3	3397.5	809.33	35.97	2.29
Mean									35.99	2.30

C3.7: C25 Compression Strength for twenty percent ceramic substitution.

Strength C25
 Mix Designation C25C20
 Ceramic substitution 20%

No	Age (days)	Ceramic waste (%)	Size of specimen (cm)			Wt. (gm)	Vol. (cm ³)	Failure Load (Kn)	Comp. Strength (Mpa)	Unit Wt. (gm/m ³)
			L	W	H					
1	7	20	15	15	15	7695.0	3375.0	598.95	26.62	2.28
2		20	15	15	15	7848.2	3397.5	588.38	26.15	2.31
3		20	15	15	15	7831.8	3420.0	585.23	26.01	2.29
Mean									26.26	2.29
1	14	20	15	15	15	7848.2	3397.5	742.73	33.01	2.31
2		20	15	15	15	7946.2	3397.5	720.45	32.02	2.33
3		20	15	15	15	7883.3	3442.5	720.23	32.01	2.29
Mean									32.35	2.31
1	28	20	15	15	15	7712.3	3397.5	852.53	37.89	2.27
2		20	15	15	15	7644.4	3397.5	855.45	38.02	2.25
3		20	15	15	15	7678.4	3397.5	859.50	38.20	2.26
Mean									38.04	2.26

APPENDIX - D4 FLEXURAL STRENGTH EXPERIMENT RESULT

D4.1: C20 Concrete Flexural strength Experiment Result

Age of testing – Twenty eighth day

No	Code	% Ceramic	Dimension (cm)			Failure load (KN)	Flexural strength (MPa)
			L	H	W		
1	C20C00	0	50	10	10	7.221	3.25
2	C20C00	0	50	10	10	7.243	3.26
3	C20C00	0	50	10	10	6.977	3.14
Mean							3.22
1	C20C10	10	50	10	10	8.843	3.98
2	C20C10	10	50	10	10	9.532	4.29
3	C20C10	10	50	10	10	9.666	4.35
Mean							4.21
1	C20C20	20	50	10	10	8.843	3.98
2	C20C20	20	50	10	10	12.487	5.62
3	C20C20	20	50	10	10	9.865	4.44
Mean							4.68
1	C20C30	30	50	10	10	7.110	3.20
2	C20C30	30	50	10	10	8.880	4.00
3	C20C30	30	50	10	10	6.999	3.15
Mean							3.45

D4.2: C25 Concrete Flexural strength Experiment Result

Age of testing – Twenty eighth day

No	Code	% Ceramic	Dimension (cm)			Failure load (KN)	Flexural strength (MPa)
			L	H	W		
1	C25C00	0	50	10	10	8.888	4.00
2	C25C00	0	50	10	10	10.910	4.91
3	C25C00	0	50	10	10	9.799	4.41
Mean							4.44
1	C25C10	10	50	10	10	11.356	5.11
2	C25C10	10	50	10	10	10.911	4.91
3	C25C10	10	50	10	10	11.133	5.01
Mean							5.01
1	C25C20	20	50	10	10	9.422	4.24
2	C25C20	20	50	10	10	15.533	6.99
3	C25C20	20	50	10	10	10.044	4.52
Mean							5.25
1	C25C30	30	50	10	10	11.222	5.05
2	C25C30	30	50	10	10	10.422	4.69
3	C25C30	30	50	10	10	11.378	5.12
Mean							4.95

APPENDIX - E5 TENSILE STRENGTH EXPERIMENT RESULT

E5.1: C20 Concrete Splitting Tensile strength Experiment Result

Age of testing – Twenty eighth day

No	Code	% Ceramic	Dimension (cm)		Failure Load (KN)	Splitting Tensile Strength (MPa)
			D	H		
1	C20C00	0	15	30	160.375	2.27
2	C20C00	0	15	30	156.843	2.22
3	C20C00	0	15	30	213.363	3.02
Mean						2.50
1	C20C10	10	15	30	187.222	2.65
2	C20C10	10	15	30	182.983	2.59
3	C20C10	10	15	30	166.734	2.36
Mean						2.53
1	C20C20	20	15	30	204.885	2.90
2	C20C20	20	15	30	170.266	2.41
3	C20C20	20	15	30	187.929	2.66
Mean						2.66
1	C20C30	30	15	30	177.332	2.51
2	C20C30	30	15	30	184.397	2.61
3	C20C30	30	15	30	180.864	2.56
Mean						2.56


E5.2: C25 concrete Splitting Tensile strength Experiment Result

Age of testing at the 28th day

No	Mix	% Ceramic	Dimension (cm)		Failure Load (KN)	Splitting Tensile Strength (MPa)
			D	H		
1	C25C00	0	15	30	254.34	3.60
2	C25C00	0	15	30	296.73	4.20
3	C25C00	0	15	30	212.66	3.01
Mean						2.60
1	C25C10	10	15	30	180.86	2.56
2	C25C10	10	15	30	227.49	3.22
3	C25C10	10	15	30	204.18	2.89
Mean						2.89
1	C25C20	20	15	30	218.31	3.09
2	C25C20	20	15	30	300.97	4.26
3	C25C20	20	15	30	219.72	3.11
Mean						3.49
1	C25C30	30	15	30	213.363	3.02
2	C25C30	30	15	30	220.428	3.12
3	C25C30	30	15	30	207.711	2.94
Mean						3.03

APPENDIX – F6 CHEMICAL COMPOSITION OF CRUSHED CERAMIC

F6.1: Chemical Composition of Crushed Ceramic Sample One (CCS01)

 <p>GEOLOGICAL SURVEY OF ETHIOPIA</p>		<p>Doc Number: GLD/FS.10.2</p>	<p>Version No: 1</p> <p>Page 1 of 1</p>
<p>GEOCHEMICAL LABORATORY DIRECTORATE</p>			
<p>Complete Silicate Analysis Report</p>		<p>Effective date: May, 2017</p>	

Customer Name:- Temesgen Kassahun Gudeta

Sample type : Ceramic

Date Submitted:- 20/01/2022

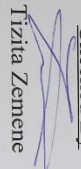
Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.


Analytical Method: LiBO₂ FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC and AAS.

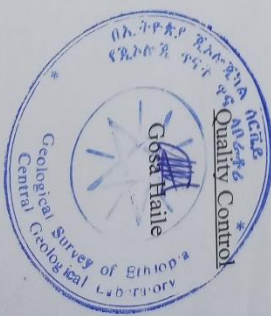
Collector's code	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	H ₂ O	LOI
Tom 123	66.26	18.56	7.44	2.48	1.68	0.48	<0.01	0.16	0.93	0.48	0.10	0.43

Note: - This result represent only for the sample submitted to the laboratory.

Analysits
 Elisa Fiseha
 Yirgalem Abraham
 Lidet Endeshaw
 Nigist Fikadu

Checked By

 Tizita Zemene

Approved By

 Yohannes Getachew


Geost Haile
 Quality Control
 Geological Survey of Ethiopia
 Central Geological Laboratory

F6.2: Chemical Composition of Crushed Ceramic Sample Two (CCS02)

		GEOLOGICAL SURVEY OF ETHIOPIA		Doc Number: GLD/E/5.10.2		Version No: 1	
		GEOCHEMICAL LABORATORY DIRECTORATE		Effective date: May, 2017		Page 1 of 1	
Document Title: Complete Silicate Analysis Report							

Customer Name:- Temesgen Kassahun

Sample type:- Ceramic

Date Submitted:- 12/07/2019

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: LiBO₂ FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC and AAS

Collector's code	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	H ₂ O	LOI
TEM-08	69.64	18.21	5.14	1.30	1.32	0.18	2.02	<0.01	0.14	0.32	0.37	0.55

Note - This result represent only for the sample submitted to the laboratory:

Analysts

Yirgalem Abriham
Tihitina Beletkachew
Tizita Zemene
Yohanis Getachew
Bethlehem Tefera

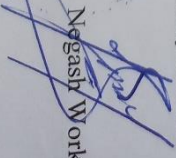
Checked By



Dessie Abebe

Approved By


Gosa Haile *

Quality Control


Negash Worku



APPENDIX – G7 SAMPLE PHOTOS TAKEN DURING THE EXPERIMENT



Photo 1. Silt Content test



Photo 2. Sieves (left) and Ball-peen Hammer (right) used to crush waste ceramic.



Photo 3. Cement (left) and aggregates weighted for mix (right).



Photo 4. Concrete ingredients before mixed (left) and after mixed (right)



Photo 5. Slump test without ceramic (left) and with ceramic (right)



Photo 6. Oiled concrete molds.



Photo 7. Vibrated Concrete specimen (left) and casted concrete samples (right)



Photo 8. Concrete specimens inside curing tank.



Photo 9. Compressive Strength test.



Photo 10. Flexural Strength test (left) and Splitting Tensile Strength test (right)