

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



**PARTIAL REPLACEMENT OF CEMENT WITH MARBLE AND CERAMIC WASTE  
POWDERS IN NORMAL STRENGTH CONCRETE**



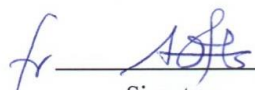

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**A Thesis in Structural Engineering**

By Rihanna Nuru  
January 17, 2022  
Addis Ababa

A Thesis  
Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled 'Partial Replacement of Cement with Marble and Ceramic Waste Powders in Normal Strength Concrete' presented by Rihanna Nuru, a candidate for the degree of Master of science, and hereby certify that it is worthy of acceptance.

|  |  |                                       |
|--|--|---------------------------------------|
| <u>Dr. Abraham Gebre</u><br>Advisor                  | <br>_____<br>Signature  | <u>March 10/2022</u><br>_____<br>Date |
| <u>Dr.-Ing. Adil Zekaria</u><br>Internal Examiner    | <br>_____<br>Signature  | <u>March 4 /2022</u><br>_____<br>Date |
| <u>Prof. Girma Zerayohannes</u><br>External Examiner | <br>_____<br>Signature  | <u>March 4/2022</u><br>_____<br>Date  |
| <u>Dr.- Ing. Mebruk Mohammed</u><br>School Dean      | <br>_____<br>Signature | <u>March 4/2022</u><br>_____<br>Date  |



### UNDERTAKING

I, the undersigned, attest that the research work titled “**Partial Replacement of Cement with Marble and Ceramic Waste Powders in Normal Strength Concrete**” is my work. Where material used from other sources has been properly referred.

Rihanna Nuru

Signature 

Date Jan7, 2021.

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## LIST OF ABBREVIATIONS

|     |                             |
|-----|-----------------------------|
| ACI | American Concrete Institute |
| OPC | Ordinary Portland Cement    |
| MWP | Marble Waste Powder         |
| CWP | Ceramic Waste Powder        |
| XRD | X-Ray Diffraction           |
| C.A | Coarse Aggregate            |
| F.A | Fine Aggregate              |

## ABSTRACT

Production of cement is hazardous to the environment. Recycling wastes has been one of the most influential aspect affecting global conditions of the world. Fair amount of work has been done on the utilization of the wastes such as marble waste, ceramic waste, tiles waste, fly ash, glass, plastic etc. used as different forms of replacement to preserve the environment. The combined effect of marble waste powder and ceramic waste powder as a partial replacement of cement is observed and analyzed. 21 cement pastes for chemical shrinkage test, 60 cube samples for compressive strength test, 60 cylinder samples for splitting tensile strength test and 21 beam members for flexural strength test with different percentages of partial replacements were made. The workability of concrete decreased with an increase of percentage replacement of cement by marble and ceramic waste powders. All of the mixes do not possess an early age cracking due to the result obtained from the chemical shrinkage test. The obtained results for compressive strength, splitting tensile and flexural strength of concrete are in the acceptable range as compared to the conventional concrete values.

## 1. INTRODUCTION

### 1.1 Background

In the construction industry, concrete is a necessary component. The demand for cement is rising as a result of the widespread use of concrete.

The production of cement is very hazardous to the environment as it produces heat and also an excessive amount of CO<sub>2</sub>. The process named calcination which is breaking down limestone (CaCO<sub>3</sub>) into free lime (CaO) and carbon dioxide (CO<sub>2</sub>) uses half the heat input of the kiln system [1]. Portland cement is made by heating a mixture of limestone which is a calcareous component and clay which is a non-calcareous component or other materials with a similar bulk composition and sufficient reactivity to around 1450°C [2]. Clinker production emits a large amount of CO<sub>2</sub>, posing a serious threat to the environment and causing long-term problems.

Efforts are being undertaken all around the globe to limit the use of concrete and replace it with other materials that have similar properties. Building waste management, which emphasizes the exploitation of industrial and agricultural wastes, is one of the primary concerns for sustainable construction.

Changes in technology, such as those resulting from depletion of existing sources of energy or raw materials, or growing realization of the need to limit environmental harm and pollution, are likely to affect the character and availability of specific industrial waste products [2].

The need of recycling waste and decreasing total energy use is becoming increasingly apparent. Concretes constructed using pulverized fuel ash and slag, as well as natural pozzolanas, can have equivalent qualities to those built with pure Portland cements at a lower cost per unit volume. Concrete built with composite cements can have qualities that are advantageous for specific applications [2].

The capacity to employ recycled waste material for concrete generates and contributes to environments' sustainability. The construction industry aspires to save costs from disposal of used wastes from industries and most importantly expenses by using recyclable and more cost-effective materials in construction.

Supplementing cementitious materials possessing either hydraulic or pozzolanic characteristics such as marble and ceramic wastes help to meet the increase demand of cement. Suitable proportions of waste materials can be used as a partial replacement of cement to produce a required strength concrete with desired workability.

The marble dust powder is resulted as a by-product of the quarrying process from the parent marble rock which is rich in calcium oxide ranging more than 50%. Due to the presence of lime, the reactivity of this marble dust powder to silica increases which can potentially be used for substituting in a cementitious binder [3]. Chemically, marbles are crystalline rocks composed predominantly of calcite, dolomite or serpentine minerals.

Ceramic wastes have good characteristics such as durability, hard and highly resistant to biological, chemical and physical degradation forces [4]. Literature reviews demonstrate that it is necessary to increase the number of studies on marble and ceramic waste to obtain eco-efficient, eco-friendly, and workable material.

Different researches show that using marble waste powder as a partial replacement shows an improvement in the workability and compressive strength up to 10% of replacement. On the other hand, ceramic waste powder also ranged up to 4% replacement for an increment of compressive strength in concrete. This paper aims in the combined effects of the marble and ceramic wastes as a partial replacement of cement and study the properties of concrete.

## **1.2 Statement of the problem**

In our country, the rate of industrial growth coupled with lack of technology for low-cost usage of construction materials leads to serious consequences in polluting the environment. Recycled wastes of different construction materials play a huge role in securing the sustainability of the environment and cost efficiency. Studies show that Marble waste has similar chemical composition with cement [5]. The chemical composition of ceramic waste powder confirmed that it possessed the pozzolanic characteristics [6]. This leads that combining the two wastes may result in an increment in percentage substitution of cement in a concrete and meeting the required standards.

### **1.3 Objectives of the study**

#### **1.3.1 General objectives**

The basic objective of this study is to investigate whether using marble and ceramic waste powders as partial replacement of cement is viable in the building industry.

#### **1.3.2 Specific objectives**

The specific objectives of this study are:

- To study the influence of percentage replacement of cement by marble and ceramic waste powder on the physical and chemical properties of Portland cement on normal strength concrete.
- To determine the workability and chemical shrinkage of concrete when cement is partially replaced with marble and ceramic waste powder at different percentages.
- To evaluate the compressive strength, splitting tensile strength and flexural strength of hardened concrete when cement is partially replaced with marble and ceramic waste powders at different percentages.

### **1.4 Scope of the study**

In this research, the role of marble and ceramic waste powders partially blended with cement for achieving the optimal and standard normal strength concrete requirements using different concrete tests were investigated.

### **1.5 Organization of the thesis**

The thesis comprises of five chapters and organized as follows.

Chapter one provides a general introduction to the thesis with a brief content of the background information and explores the rationale of the research by highlighting the main issues associated with cement production and partial replacement with supplementary materials, objectives and scope as well as the organization of the thesis. Chapter two revise the relevant literature, and quotes the various related works done in the study area. Chapter three presents the materials, methods and testing procedures used for the accomplishment of the research. Chapter four attempts to describe in detail the results of the experiments,

followed by discussions of the findings. Finally, Chapter five includes conclusions and recommendations of the study.

## 2. LITERATURE REVIEW

### 2.1 Introduction

In this chapter, the review of relevant literature on cement replacement, waste materials and partial replacement of cement with marble and ceramic waste powders are discussed.

### 2.2 Concrete

Concrete is mainly a combination of two ingredients. Portland cement with water making the paste is the first main ingredient. The paste constitutes about 25% to 40% of the total volume of concrete. The second main ingredients are aggregates which are typically sand and gravel or crushed stone. The paste hardens and binds the aggregates into a rocklike mass as the cement and water react chemically. The paste and aggregate including the bond in between them determines the quality of the concrete. The aggregate particles are completely coated and all of the spaces in between them with paste in a suitably prepared concrete. The quality of the paste and aggregate merged with the bond between the two determines the quality of the concrete in general [7].

The amount of water used in relation to the amount of cement used in hardened concrete is strongly influenced by the amount of water used in relation to the amount of cement used in any particular set of materials and curing conditions. Unnecessarily high water contents dilute the glue of concrete which is cement paste. The higher the quality of the concrete, the less water it takes to make it. Smaller amounts of mixing water result in stiffer mixtures; but with vibration, stiffer mixtures can be easily placed.

#### 2.2.1 Components of Concrete

The main components of concrete are cement, fine aggregate, coarse aggregate and water.

##### 2.2.1.1 Cement

Cements are adhesive compounds that may bind together fragments or masses of solid matter to form a compact whole [1].

Hydraulic calcium silicates are the primarily components of Portland cements which are hydraulic. Hydraulic cements react chemically with water to set and harden in a reaction called hydration. Cement and water combine to form a paste that resembles a stone and which

acts as an adhesive and binds the aggregates together to form concrete. Where concrete is the world's most widely used and most versatile construction material [7].

### 2.2.1.1.1 Manufacture of Portland cement

Portland cement is manufactured by pulverizing clinker. The clinker consists mainly of hydraulic calcium silicates. In addition it contains some calcium aluminates, calcium alumino-ferrites and one or more forms of calcium sulfate (gypsum). The calcium, silica, alumina, and iron components in the materials required to make Portland cement must be in the proper proportions. A uniformly high quality of cement is ensured by a frequent chemical analyses of all materials are made during manufacture [7].

Between 95 and 97 percent of calcination is finalized in a pre-calciner kiln before the meal leaves the lowest stage cyclone which is the process of breaking down  $\text{CaCO}_3$  into  $\text{CaO}$  and  $\text{CO}_2$ . Free lime (FL) which is the unreacted  $\text{CaO}$  levels in hot meals show that some of it reacts with silicate minerals in the calciner. This occurs especially when the calcareous raw material is not pure and each hot meal particle encompasses both  $\text{CaO}$  and silicates in intimate contact [1].

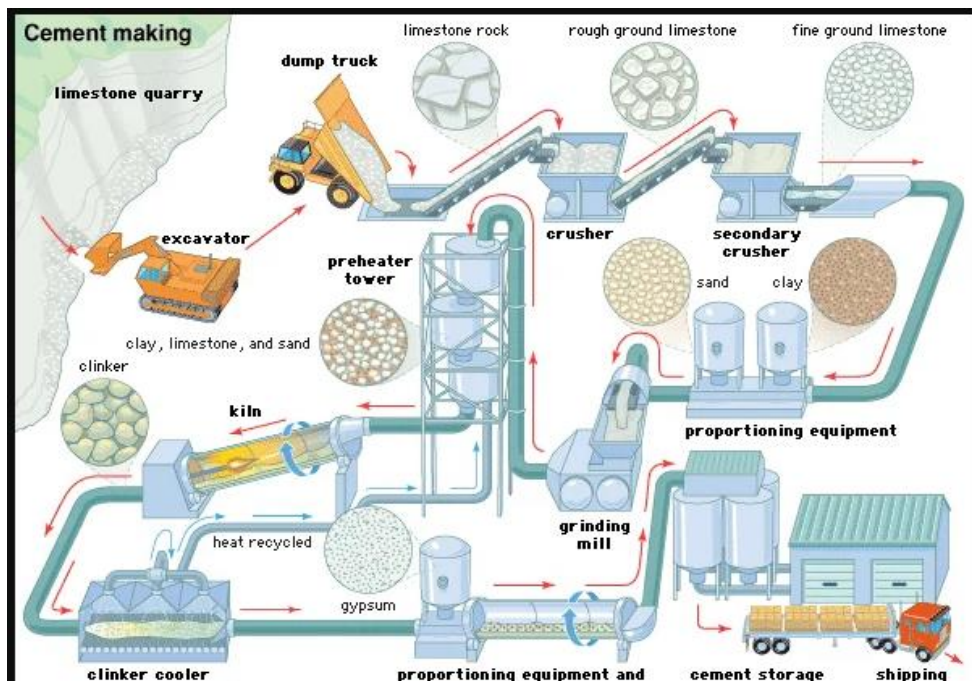


Figure 2.1 Production of Cement

The processes that produce alite and belite in the kiln are affected by temperature and residence time. Clinker achieves a temperature of between 1350°C and 1450°C in the burning zone. Clinker typically has a FL content of 1% to 2% [1].

#### **2.2.1.1.2 Physical properties of cement**

Cement specifications bounds both on its physical properties and often on its chemical composition. In interpreting the results of cement tests, understanding the significance of some of the physical properties is helpful. The properties of cement are limited by their specifications, which are based on the type of cement. Cement is continuously monitored and followed up for its chemistry and the following properties during manufacture [7].

##### **a. Particle Size and Fineness**

The "fineness" of cement refers to the total particle size distribution which affects heat released and hydration rate. Greater cement fineness which is lower particle size promotes strength development by increasing the rate at which cement hydrates. The effects of fineness on paste strength are most noticeable within the first seven days. Fineness is a measure of surface area of cement particles per unit mass indirectly which indicates that cements with finer particles have more surface area. The outcome of pulverizing clinker in a grinding mill is Portland cement, which is made up of individual angular particles of various sizes. Cement particles have an average particle size around 15 micrometers where approximately 95% of cement particles are smaller than 45 micrometers [7].

##### **b. Normal Consistency**

The ability of a freshly mixed cement paste or mortar to flow is referred to as consistency. As stated in ASTM C 187, a normal consistency of a paste during a cement testing is prepared where the Vicat plunger penetration of  $10 \pm 1$  mm is indicated. In order to control the amount of water in pastes, the normal consistency technique is used. This also allows in comparing dissimilar ingredients having the same penetrability [7].

##### **c. Setting Time**

The aims of performing setting time are to determine the initial set and final set of paste. Initial set is the time that counts from the moment water is added till the paste ceases to be fluid whereas final set is the time needed for a paste to attain a certain degree of hardness.

This test is performed to determine if a cement sets based on the time limits in cement specifications using either the Vicat apparatus or the Gillmore needle in ASTM C 191 or AASHTO and ASTM C 266 or AASHTO 154 respectively [7].

#### **d. Specific Gravity (Density and Relative Density)**

The mass of a unit volume of the particles or solids excluding air in between the particles is termed as the density of cement. It is expressed as mega grams per cubic meter. The cement density obtained using ASTM C 188 or AASHTO T 133 does not indicate the quality it has, rather its basic use is in calculations for mixture proportioning. It may be more advantageous to express the density as relative or specific gravity which is a dimensionless number obtained by dividing the cement density by density of water at 4°C (1.0 g/cm<sup>3</sup> or 1000 kg/m<sup>3</sup>). Portland cement has particle density ranging from 3.10 to 3.25 with an average value of 3.15 Mg/m<sup>3</sup> which is used in volumetric computations of concrete mix proportioning [7].

#### **e. XRD**

The quantitative and qualitative determination of phase composition, polymorphic modification, state of crystallinity and other individual phase features are the potential uses of XRD power diffraction in the study of clinker and anhydrous cement. In the pattern of a typical Portland cement where peaks and phases are assigned, alite is normally so much predominant phase that its pattern tends to swamp other phases. The alite peaks overlaps that of all the stronger peaks of belite [2].

#### **2.2.1.2 Aggregate**

Concrete can be taken as two phase materials: paste phase and aggregate phase. Aggregates are the vital constituents in concrete that gives body to the concrete and reduce shrinkage. Unlike the earlier times where aggregates were considered as inert materials, they now are recognized as chemically active materials that exhibit chemical bond at the interface of aggregate and paste. Since they occupy the major part of concrete, the study of the aggregate shall be in depth and range to make the study of concrete complete [8].

About 60% to 75% of the entire volume which is 70% to 85% by mass of concrete is consisted of aggregates, indicating that choosing the right one is vital. The particles in aggregates should be resistant to exposure and should not contain any components that may

cause the concrete to weaken. A constant gradation of aggregate particle sizes is desired for an optimal usage of the paste [7].

Two groups of aggregates exist: fine and coarse. To improve the overall aggregate gradation, an intermediate –sized aggregate is added which is around 9.5 mm. Fine aggregates embrace manufactures or naturally existing sand with particle sizes ranging up to 9.5 mm. Coarse aggregates are those particles ranging up to 150mm and retaining on the 1.18 mm or No. 16 sieve [7].

### **2.2.1.3 Water**

Water participates in the chemical reaction with cement that makes it an important ingredient of concrete. The quality of water should be of a great attention since it helps to form the strength giving cement paste. The suitability of water for mixing concrete is that for it to be potable, but this does not appear to be true for all conditions [8].

### **2.3 Workability of Concrete**

Workability is the ease of placing, consolidating and finishing of a freshly mixed concrete to which it resists segregation. The placement method, type of consolidation and the type of concrete control the degree of workability required for proper placement of concrete [7].

Consistency, segregation, mobility, pump ability, bleeding and finish ability are properties related to workability. Consistency is considered as a good predictor of workability. Slump is a measurement of concrete's consistency or wetness. A low-slump concrete has a rigid consistency. The concrete will be so tough to place and compact resulting of the larger aggregate particles separate from the mix, if the consistency is too dry or harsh. Segregation and honey combing may occur, if the concrete mix is too wet [7].

### **2.4 Hydration of Concrete**

Hydration is a chemical reaction between cement and water leading in the binding quality of Portland cement. 90% or more of the weight of Portland cement is made from tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite compounds. These four compounds are present in each type of Portland cements in different proportions. Several others play important roles in the hydration process in addition to these major compounds. Most of the individual cement compounds can be recognized and their amounts

determine when the kiln product that is ground to make Portland cement is observed under a microscope even though the smallest grains escape visual detection. Approximately 15 micrometers is the average diameter of a typical cement particle [7].

About 75% of the weights of Portland cement are the two calcium silicates that react with water to form calcium hydroxide and calcium silicate hydrate. Calcium silicate hydrate is by far the most important cementing in concrete which contains lime (CaO) and silicate (SiO<sub>2</sub>) in 3 to 2 ratio. Engineering properties such as: Setting, hardening, strength and dimensional stability basically rely on calcium silicate hydrate. It also forms dense, bonded aggregations between other crystalline phases and the remaining un-hydrated cement grains, grains of sand to pieces of coarse aggregate cementing together in hardened cement paste. Its gross volume remains almost unchanged as concrete hardens, but pores filled with water and air that have no strength are contained in hardened concrete. The solid part of the paste has the strength which is mostly carried by the calcium silicate hydrate and crystalline compounds [7].

When cement comes into contact with water, it begins to hydrate. On the surface of each cement particle, a fibrous growth occurs, which gradually expands until it connects with the growth of other cement particles or clings to nearby items. This fibrous buildup causes stiffness, hardness, and strength progressively. Concrete stiffening is identified by a loss of workability that occurs within three hours after mixing, but is dependent on the cement composition and fineness, any admixtures used, mixture proportions, and temperature conditions where eventually the concrete sets and becomes hard [7].

## **2.5 Strength of Concrete**

Testing hardened concrete is crucial for ensuring and regulating the quality of cement concrete projects. Testing hardened concrete has several objectives, one of which is to ensure that the concrete used on site has attained the requisite strength. The concrete strength is its resistance to rupture, which can be measured in a variety of ways, including compression, tension, flexure, and shear. Particular method of testing is used to indicate the strength of all these. Among the purposes of testing hardened concrete one is that to confirm that concrete used at site has developed the required strength. Failure is essentially a mixture of crushing and shear failure when concrete fails under a compressive load [8].

### **2.5.1 Compressive strength of concrete**

The most common test on hardened concrete is the compression test, partly because it is a simple test to perform and partly because most of the desirable characteristics of concrete are qualitatively related to its compressive strength. Concrete is employed primarily to resist compressive stresses in most of structural applications. Compressive strength is one of the most relevant and beneficial properties of concrete [8].

The measured maximum resistance of concrete specimen to axial loading is defined as Compressive strength which is expressed in Mega Pascal (MPa) at the age of 28 days. It is a primary physical property which is used in design calculations for buildings, bridges and other structures. Cement type, compound composition and fineness of the cement influence the compressive strength. Concrete compressive strength is a result from water to cement ratio, water to cementitious materials ratio, the extent to which hydration has improved, curing, environmental conditions and the concrete age. About 75% of the 28-day strength is often estimated as seven-day strengths and about 10% to 15% greater than 28-day strengths are often estimated as 56-day and 90-day strengths [7].

### **2.5.2 Splitting tensile strength of concrete**

The test for determining the splitting tensile strength of concrete is straightforward and produces more consistent results than other tension tests. The results obtained from the splitting tensile strength test are assumed to be closer to the true tensile concrete strength than the ones obtained from the modulus of rupture. The splitting test yields a 5 to 12 percent higher rating than the direct tensile strength test [8].

### **2.5.3 Flexural strength of concrete**

Concrete is comparatively strong in compression and weak in tension where a little dependence is placed on the tensile strength of concrete in reinforced concrete members since all tensile forces are resisted by providing steel reinforcing bars. Nevertheless the knowledge of tensile strength of concrete is relevant since tensile stresses are likely to develop in concrete cracking due to drying shrinkage, temperature gradients, rusting of steel reinforcement and many other reasons [8].

Modulus of rupture or flexural strength of concrete is used to design pavements and other slabs on ground [7].

## **2.6 Volume changes of concrete**

Volume change is simply described as an increase or reduction in volume, which may happen for a variety of causes in concrete. For planning or analyzing of concrete work, understanding the nature of these changes is helpful. Volume changes would have slight consequence, if concrete were free of any restraints to deform. Significant stresses can develop since concrete in service is usually restrained by foundations, subgrades, connecting members or reinforcement which is particularly true of tensile stresses. Concrete is relatively weak in tension but strong in compression which may result in the development of cracks. The structural design should consider tolerable crack widths. High stresses and cracking can be minimized by controlling the variables that affect volume changes. Basically, the issue of volume changes of concrete deals with linear expansion and contraction as a result of temperature and moisture cycles. But volume changes may also be caused by chemical effects such as carbonation shrinkage, sulfate attack and the disruptive expansion of alkali-aggregate reactions. Sustained stress or load causes creep which is also a volume change or deformation. The elastic or inelastic change in dimensions or form that occurs instantaneously under applied stress is also significant. For suitability, linear units are used to state the magnitude of volume changes rather than volumetric units. Parts per million is used to express the changes in length which are often expressed as a coefficient of length. Length change can also be stated as a percentage, thus 0.06% is the same as 0.000600. Concrete volume changes that ordinarily occur are small, ranging from possibly 10 millionths up to about 1000 millionths in length change [7].

### **2.6.1 Early age volume changes**

Concrete volume begins to alter soon after it is cast. Early volume fluctuations within 24 hours can affect changes in volume of the hardened concrete such as drying shrinkage and crack formation [7]. Various forms of early volume change exist where some are discussed below.

#### **2.6.1.1. Chemical Shrinkage**

Chemical shrinkage is defined to be the reduction in absolute volume of solids and liquids in paste which is resulted from hydration of cement. Le Chatelier (1900) was the first to study chemical shrinkage of cement pastes. The absolute volume of cement and water before hydration is greater than the absolute volume of hydrated cement products. Figure 2.1 shows

the volume change of cement paste during the plastic state. The first two bars in the figure do not include air bubbles resulting from mixing. As long as cement hydrates, chemical shrinkage continues to occur at a microscopic scale. The paste cannot distort as much as when it was in a plastic state after initial set [7].

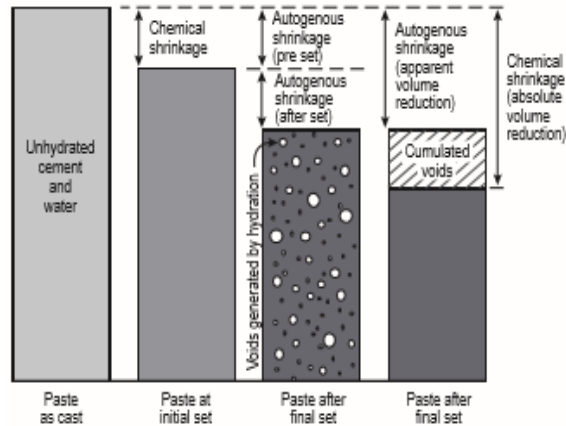


Figure 2.2 Chemical shrinkage and Autogenous shrinkage

As shown in the figure 2.1, the creation of voids in the microstructure compensates for additional hydration and chemical shrinkage. This volume change does not significantly change the visible external dimensions of a concrete element rather is mostly internal. The hydrated cement phases and their crystal densities or physical test can estimate the amount of volume change due to chemical shrinkage. The physical test is illustrated in Figure 2.2 showing flask for cement paste and pipet for absorbed water measurement [7].

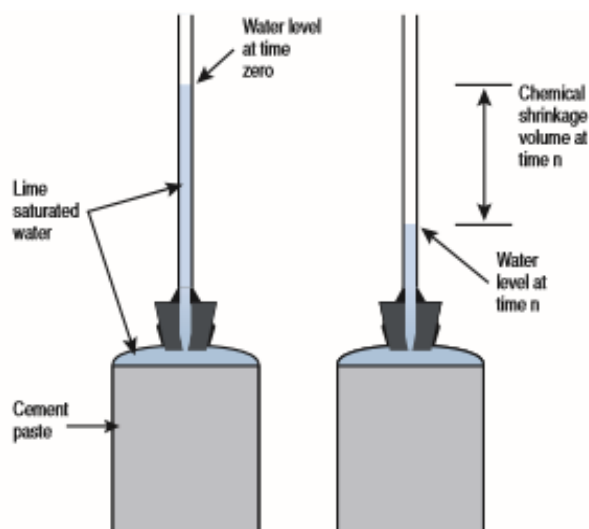


Figure 2.3 Test for chemical shrinkage of cement paste

### 2.6.1.2 Autogenous Shrinkage

The visible dimensional change or the macroscopic volume reduction of cement paste, mortar or concrete caused by cement hydration is referred to as Autogenous shrinkage which is much less than the absolute volume reduction of chemical shrinkage due to the hardened paste structure. Some researchers and organizations believe autogenous shrinkage begins at the time of placement, while others believe it begins at the time of initial set. Cement hydration consumes water existing in pore resulting in self-desiccation of the paste and uniform volume reduction when external water is not available. Autogenous shrinkage is driven by the force of chemical shrinkage where it increases with an increase in the amount of cement paste and a decrease in water to cement ratio. Figure 2.3 illustrates the relationship between chemical and autogenous shrinkage has [7].

Autogenous shrinkage is more projecting in concrete with a water to cement ratio under 0.42 and is negligible in normal concrete. For concretes with a water to cement ratio of 0.3, autogenous shrinkage can be half that of drying shrinkage. 200 to 400 millionths of autogenous shrinkage is experienced in high strength of concrete with low water to cement ratio (0.3). In order to control crack development in bridges and other structures, recent use of high performance concrete with low water to cement ratio has renewed interest [7].

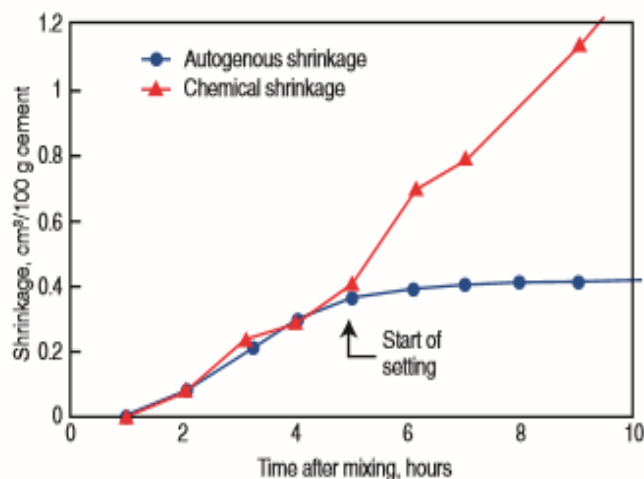


Figure 2.4 Relationship between Autogenous shrinkage and chemical shrinkage of cement paste early ages.

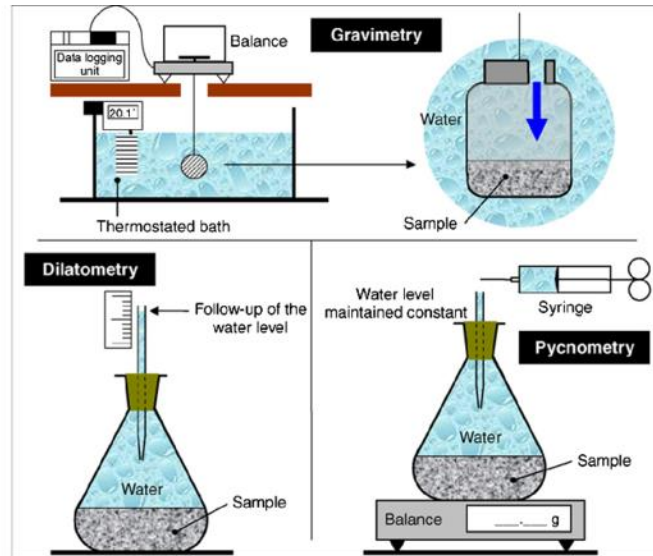


Figure 2.5 Process for chemical shrinkage test

To assist control crack formation, concretes susceptible to substantial quantities of autogenous shrinkage should be cured with external water for at least 7 days.

Autogenous shrinkage is contributed by the hydration of supplementary cementing materials at different degrees than Portland cement. Autogenous expansion may be experienced by some cementitious systems. Autogenous shrinkage can be reduced by adjusting paste content, regulating water to cement ratios and by using shrinkage reducing admixtures or internal curing techniques.

## 2.7 Supplementary Cementitious Materials

Extending cement using Secondary Cementitious Materials (SCMs) like as silica fume, metakaolin and rice husk ash is one of the main success stories of the last 40 years in having a role to replace or enhance the use of Portland cement. Certainly, the testing of newly discovers cementitious materials and the effects of mixing dominate modern cement research [1].

Up to 5% of additional materials such as slag, fly ash or limestone can now be contained in cements and still be called as Portland cement. By merging these ingredients in higher amounts, as many as 27 common cements can now be set as standard [1].

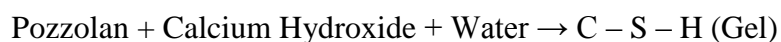
As part of the complete cementitious system, supplementary cementitious elements are added to concrete. Depending on the properties of the materials and the desired effect on concrete,

SCMs may be used in addition or as partial replacement of Portland cement or blended cement in concrete. They can also be utilized to improve a specific concrete quality, such as alkali-aggregate reactivity resistance. Test should be done to establish the optimum amount of using SCMs to determine if the material is indeed advancing the property and to regulate the correct dosage rate in avoiding an overdose or under dose which may be harmful or not achieve the desired effect. The supplementary cementitious materials react differently with different cements. Fly ash, slag, calcined clay, calcined shale, and silica fume were traditionally used independently in concrete. Due to improved access to these materials, concrete producers can now combine two or more of them to improve concrete properties [7].

### 2.7.1 Natural pozzolanas

Pozzolanic materials are siliceous or siliceous and aluminous materials that have little or no cementitious value on their own. There are two types of pozzolanic materials. Natural pozzolanas such as: Clay and Shales, Opalinc Cherts, Diatomaceous Earth, Volcanic Tuffs and Pumicites and Artificial pozzolanas such as: Fly ash, Blast Furnace Slag, Silica Fume, Rice Husk ash, Metakaoline and Surkhi. Mineral admixtures like finely ground marble, quartz, granite powder are also used that neither exhibit the pozzolanic property nor the cementitious properties rather act as inert filler [8].

In finely divided form and in moisture presence, they react chemically with calcium hydroxide liberated on hydration to form compounds owning cementitious properties at conventional temperature. One of the byproducts of hydration is calcium hydroxide on hydration of tri-calcium silicate and di-calcium silicate. This compound is soluble in water and has no cementitious value where it may be leached out by the percolating water. The siliceous or aluminous chemical reacts with calcium hydroxide in finely split form to generate very stable cementitious compounds including calcium, silica, and water. The pozzolanic reaction can be represented as follows:



This reaction has a number of distinguishing characteristics, the first of which is its slowness, which is reflected in the heat of hydration and the rate at which strength develops. The consumption of  $\text{Ca}(\text{OH})_2$  is involved in the reaction not the production where it improves the durability of cement paste by making the paste dense and impervious. Calcium hydroxide, a

water soluble material is converted into insoluble cementitious material by the reaction of pozzolanic materials. In general, amorphous silicate responds faster than crystalline form. [8].

Optimizing the shielding properties of strength – enhanced concrete containing marble aimed in developing a low cost, locally produced concrete mixture with optimum marble content. The resulting mixture has improved strength qualities and radiation shielding properties when compared to the non-marble reference concrete. The compressive strength of concrete containing marble increases as the marble content increases, until it reaches an absolute maximum value at a marble cement-replacement ratio of 10 %. Beyond 10% of replacement, it starts to decrease as the marble content increases [9].

A research on concrete mixes with partial replacement of cement with waste marble powder and natural sand by artificial sand targets on 28 compressive strength of 20MPa. More water was required for workability due to the rough texture of artificial sand and the significant number of small particles in waste marble powder, both of which necessitated more water to wet, resulting in a decrease in workability. Experimental results show that workability does affect due to artificial sand and 20% waste marble powder gives optimum strength in a mortar. Fine marble powder increases binding property of concrete resulting in the addition of compressive strength of concrete. A noticeable impact due to the artificial sand was observed on the compressive strength. A standard equation was generated via regression approach to infer the strength of concrete with waste marble powder. The observed values produced by the suggested equation are in good compatibility with the real results. [5].

Partial replacement of Portland slag cement with marble dust powder at different percentage of concrete resulted in 10% replacement of cement for compressive strength, up to 15% for split tensile and flexural strength of concrete. Environmental issues emerge from waste created by companies, and the importance of reusing these resources cannot be overstated. Marble dust powder is one of the major wastes produced in the stone industry during cutting, shaping and polishing of marbles where about 20-25% of this process turns marble to the powder form. It is creating composite materials that will help the concrete industry to better use materials, produce economic benefits, and construct structures that are strong, long-lasting, and environmentally conscious [3].

As cement is a useful ingredient of concrete mix, it is also environmentally hazardous due to its production emits a huge amount of CO<sub>2</sub>. The current study aims to use ceramic waste

powder to partially replace cement in concrete since its chemical composition indicates that it has pozzolanic properties. This will lessen the environmental impact of CO<sub>2</sub> emissions and landfill deposition of ceramic waste powder. Concrete specimens along with those containing 10 % and 20 % partial replacement of cement by ceramic waste powder and the results revealed that a 10% replacement of ceramic powder causes a decrease of 11% in compressive strength at 28 days even though workability increased [6].

In terms of disposal and impact on the environment, waste materials have become major concern. Many studies looked at the use of pozzolanic waste materials in concrete and how they improved the strength and durability of the material. The problem of waste materials is aggravated by the discarding of some wastes, such as ceramic tiles, after they have been used. In certain preliminary experiments, ceramic waste has been identified as a viable pozzolanic material. About 84.8% of the total oxides consist of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> in a mortar mix that used ceramic waste powder. Ceramic waste powder material has higher percentages of silicate and aluminate which indicates potential pozzolanic reactivity when integrated in mortar or concrete mixes. The findings show that ceramic waste powder may be utilized as a partial replacement for cement and can improve the qualities of mortar. Workability of mortar containing 20% ceramic waste powder is improved up to 22% compared to normal mortar and mortar containing 20% ceramic waste powder as cement replacement has shown higher compressive strength as compared to normal mortar by 8%. This was probably as a result of pozzolanic reactions between ceramic waste powder and calcium hydroxide from the hydration of cement [12].

A study emphasize on reusing of broken ceramic tiles in the form of ceramic waste powder to be used as binding material to replace cement in mortar. The influence of ceramic waste powder on the mechanical characteristics (compressive and tensile strength) of mortar has been studied at various curing times. As the percentage of ceramic waste powder increase, decrement of compressive and tensile strength of mortar has been observed, though there is no significant reduction of strength up to 20% of cement replacement by ceramic waste powder [13].

Ceramic waste is one of the wastes in any construction project, whether it is discarded waste or the residues of building materials that are no longer in use. Ceramic waste is the one that had no selling value. The effect of using ceramic waste powder as a substitute for cement on the compressive strength of K250 concrete concluded that the best percentage composition is

3% with an average compressive strength value of 330.99 kg / cm<sup>2</sup>, as well as the 4% percentage has a compressive strength of 243.89 kg / cm<sup>2</sup> and in the percentage of 5% has a value of 258.41 kg / cm<sup>2</sup>. The more ceramic waste is substituted for cement, the lower the compressive strength of concrete [14].

To improve the mechanical properties of cement with waste marble powder by incorporating Nano silica, an attempt has been done in a study. With a replacement ratio of more than 10%, waste marble powder enhanced the fluidity and extended the setting time of pastes, but it considerably lowered the compressive strength [15].

To contribute to the marble industry, ecology and economy, it is essential to prioritize recycling applications. The adverse impacts of waste marble on the environment are decreased by researching the impact of marble waste on concrete strength and thoroughly investigating recycling possibilities based on a review of previous research. As indicated by the results, the use of waste marble in concrete in certain rates was sufficient to replace cement, fine/coarse aggregate and admixture material where exhibited higher strength of concrete is obtained. In the current investigations, practical equations were established to compute the compressive strength and splitting tensile strength of concrete including waste marble. The calculated and measured values for both compressive and splitting tensile strength obtained a fairly good fit. The scientific significance of the work was demonstrated by a demonstration that showed that using waste marble in concrete manufacturing is helpful and offered useful equations for determining the compressive and splitting tensile strength of concrete without experimentation. A review based on strength of concrete containing marble waste resulted that the optimum replacement rate was 10% of waste marble powder as a substitute for cement in concrete. Thus, the cement with optimal concrete strength was obtained by using 10% waste marble replacement for cement [16].

Due to the rapid growth of the global population and the need to fulfill consumer expectations, solid waste landfills will continue to receive large amounts of waste. Converting these large amounts of solid wastes into an alternative resource will assist to save nonrenewable resource materials, sustain essential energy, and tackle environmental and landfill concerns. Ceramic waste powder particles are similar to those of cement in shape and included more than 85% SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>. Ceramic waste powder has the potential to be utilized as a partial replacement for cement in the production of sustainable and cost-effective

combinations, based on its properties. All mixtures with ceramic waste powder showed good strength development at 90 days of age and decreased afterwards [17].

The goal of the present research is to determine the technological and regulatory viability of employing marble industry waste as a Portland cement ingredient. Physicochemical analysis and mineralogical composition of the marble dust confirm that it is a pure and clean by-product based on the presence of CaO, as determined by the findings. Compression resistance is higher in samples with marble dust percentage additions of up to 10% than in the control series. Compression resistance at curing ages of 90 and 365 days is greater than 50% of reference resistance values at 28 days [18].

The percentage of ceramic waste generated from the production is about 15-30% further to the waste obtained from the construction field as investigated in various researches done. Ceramic waste reuse is little, but if it were done, it would be one of the alternative options for ensuring building sustainability. It is feasible to use the ceramic waste as cement replacement in grade M25 concrete. Because the compressive strength slightly increases with the concrete represent up to 30% ceramic waste form cement weight, the compressive strength of normal concrete was 33 MPa after 28 days whereas it was 34 MPa for concrete with ceramic waste after the same period. Furthermore, the concrete consists 30% of ceramic waste as replacement of cement is saving 16% from the total cost of the convention concrete [19].

The above researchers have worked on marble and ceramic waste powder individually. This study focused on investigating the blended effects of cement with marble and ceramic waste powder for better percentage of partial replacement due to that the marble waste powder has similar chemical composition with cement and ceramic waste powder posse pozzolanic reactivity.

## **2.8 Gap identification**

Many researchers are striving to find partial cement substitutes using environmentally friendly materials. Some use marble waste powder due to the fact that it has similar chemical properties with cement and some use ceramic waste powder due to its pozzolanic behavior. Blending marble and ceramic waste powder with cement together regarding the mentioned advantages, results in attaining more percentage replacements than the individually obtained results as well as meeting the ranges of the standards.

### 3. MATERIALS AND METHODS

#### 3.1 Introduction

In this chapter, material types and properties, sample preparations, experimental procedures, test setups used in the study and all the laboratory tests carried out are briefly described. The preparations of materials, the tests and the experimental detailed programs were conducted in Addis Ababa Institute of Technology (AAiT) construction material laboratory. The requirements set in ASTM standards and specifications were used to check the material properties and the testing.

#### 3.2 Materials

The materials used for this research includes cement, fine aggregate, coarse aggregate, water, marble waste powder and ceramic waste powder.

##### 3.2.1 Cement

For this study, Ordinary Portland cement was used which was commercially available in the local market. The cement used is a Type-1 Dangote with CEM 42.5R grade with the relative density of  $3.15\text{g/cm}^3$ . The physical properties have been examined and summarized in Table 3.1.

Table 3.1 Physical properties of cement

| Item No. | Description                                    | Test result                |     |
|----------|--|----------------------------|-----|
| 1        | Fineness of cement ( $\text{cm}^2/\text{gm}$ ) | 2850                       |     |
| 2        | Specific gravity                               | 3.15                       |     |
| 3        | Normal consistency test                        | Water to cement ratio (%)  | 27  |
|          |  | Water (gm)                 | 135 |
|          |  | Penetration (mm)           | 10  |
| 4        | Setting time                                   | Initial setting time (min) | 75  |
|          |  | Final setting time (min)   | 290 |

### 3.2.2 Aggregate

The term aggregate encompasses both fine and coarse aggregates. Three quarters of the volume of concrete is covered by aggregates. Same source was used to the supply of the aggregate to eliminate any variations that may occur in using different sources. All the necessary laboratory tests such as bulk density, specific gravity and moisture content of the aggregate have been carried out to warrant that the material meets the specification for the concrete work. In doing so, the aggregate has been washed to remove impurities like silt and any other dust that may cause quality reduction. Then after, the aggregate was kept with a plastic bag to sustain the moisture content till the time of mixing.

#### 3.2.2.1 Fine Aggregate

A small-size filler material that passes through 4.75mm and retains on 0.07mm sieve is used as a fine aggregate in concrete [20]. For this research, a fine aggregate that passes through a 4.75mm sieve was used. Table 3.2 summarizes the test results of the physical properties of fine aggregates done in the laboratory.

Table 3.2 Physical properties of fine aggregate

| No. | Test description    |            | Test result               |
|-----|---------------------|------------|---------------------------|
| 1   | Silt content        |            | 1.33%                     |
| 2   | Moisture content    |            | 1.523%                    |
| 3   | Absorption capacity |            | 2.27%                     |
| 4   | Fineness modulus    |            | 2.6                       |
| 5   | Unit weight         |            | 1490.97 kg/m <sup>3</sup> |
| 6   | Specific gravity    | Bulk       | 2.453 g/cm <sup>3</sup>   |
|     |                     | Bulk (SSD) | 2.51 g/cm <sup>3</sup>    |
|     |                     | Apparent   | 2.597 g/cm <sup>3</sup>   |

Table 3.3 The particle size distribution of fine aggregate

| Sieve size(mm) | Weight retained (gm) | Percent retained (%) | Cumulative retained (%) | Cumulative passing (%) | ASTM C33 standard passing range (%) |
|----------------|----------------------|----------------------|-------------------------|------------------------|-------------------------------------|
| 9.75           | 0.2                  | 0.04                 | 0.04                    | 99.96                  | 100                                 |
| 4.75           | 0.3                  | 0.06                 | 0.1                     | 99.9                   | 95-100                              |
| 2.36           | 27.9                 | 5.58                 | 5.68                    | 94.32                  | 80-100                              |
| 1.18           | 70.9                 | 14.18                | 19.86                   | 80.14                  | 50-85                               |
| 0.6            | 143.8                | 28.76                | 48.62                   | 51.38                  | 25-60                               |
| 0.3            | 188.8                | 37.76                | 86.38                   | 13.62                  | 5-30                                |
| 0.15           | 56.2                 | 11.24                | 97.62                   | 2.38                   | 0-10                                |
| Pan            | 8.3                  | 1.66                 | 99.28                   | 0.72                   | 0                                   |

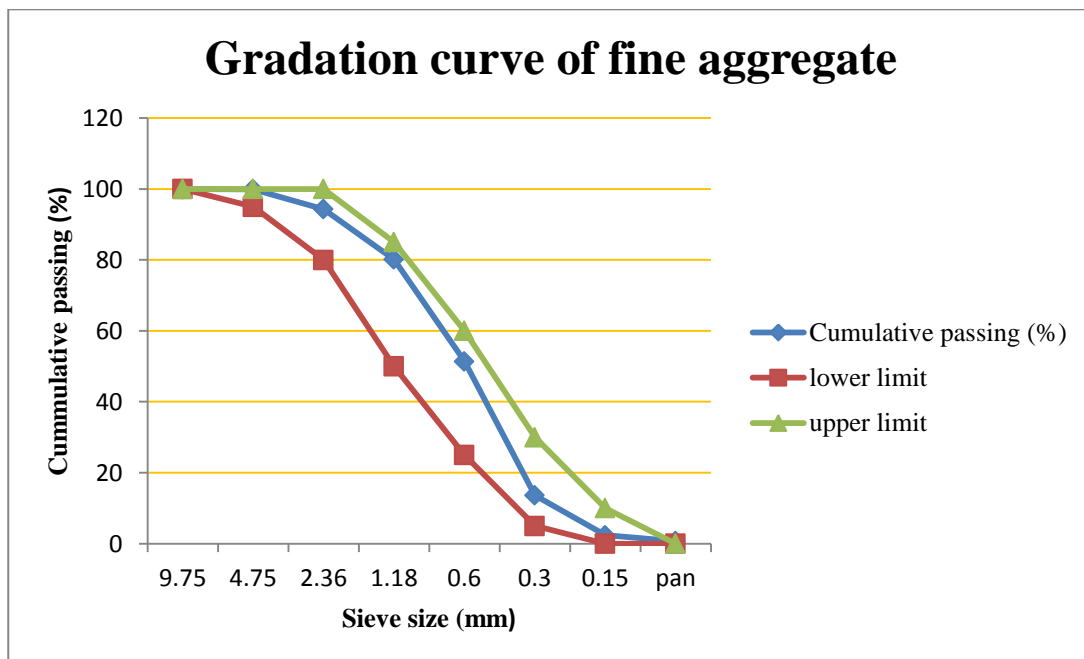


Figure 3.1 Gradation curve of fine aggregate

In order to remove the silt content of the fine aggregate having original silt content of 7% to 1.33%, it has been washed. The fine aggregate obtained locally for this study satisfies the requirement from ASTM C-33-01 [21].



Figure 3.2 Silt content of fine aggregate

### 3.2.2.2 Coarse Aggregate

Basaltic crushed rock coarse aggregate has been used for this research which was obtained from a local material supplier. Coarse aggregates with 9.5mm, 12.5mm, 19mm and 25mm were used. The following Table 3.4 and Figure 3.3 below summarize the physical properties obtained from the laboratory test results.

Table 3.4 Physical properties of coarse aggregate

| No. | Test description    | Test result            |                         |
|-----|---------------------|------------------------|-------------------------|
| 1   | Moisture content    | 2.03%                  |                         |
| 2   | Absorption capacity | 1.4525%                |                         |
| 3   | Fineness modulus    | 6.94                   |                         |
| 4   | Unit weight         | 1669 Kg/m <sup>3</sup> |                         |
| 5   | Specific gravity    | Bulk                   | 2.635 g/cm <sup>3</sup> |
|     |                     | Bulk (SSD)             | 2.673 g/cm <sup>3</sup> |
|     |                     | Apparent               | 2.739 g/cm <sup>3</sup> |

Table 3.5 The particle size distribution of fine aggregate

| Sieve size(mm) | Weight retained (gm.) | Percent retained (%) | Cumulative retained (%) | Cumulative passing (%) | ASTM C33 standard passing range (%) |
|----------------|-----------------------|----------------------|-------------------------|------------------------|-------------------------------------|
| 25             | 0                     | 0                    | 0                       | 100                    | 95-100                              |
| 19             | 131.2                 | 6.56                 | 6.56                    | 93.44                  | -                                   |
| 12.5           | 882                   | 44.1                 | 50.66                   | 49.34                  | 25-60                               |
| 9.5            | 736.2                 | 36.81                | 87.47                   | 12.53                  | -                                   |
| 4.75           | 247                   | 12.35                | 99.82                   | 0.18                   | 0-10                                |
| pan            | 3.6                   | 0.18                 | 100                     | 0                      | 0                                   |

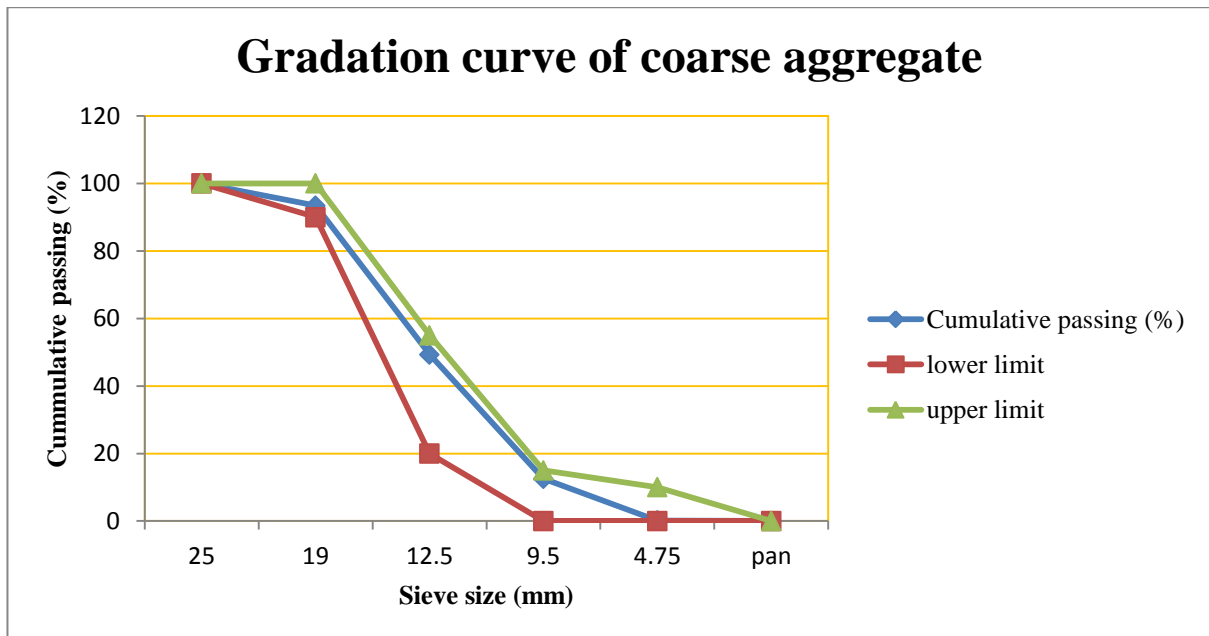


Figure 3.3 Gradation curve of Coarse aggregate

### 3.2.3 Water

Water is a vital component of concrete as it strongly plays a part in the chemical reaction with cement. It is also used in washing the aggregate and curing of concrete. For these reasons, the water should be free from impurities, alkalis, suspended solids, silt and dissolved solids that may degrade its quality. The water used for this study is tap water from the construction material laboratory of Addis Ababa Institute of Technology water supply pipe.

### 3.2.4 Marble Waste Powder

Enormous amount of marble waste powder is released in shaping marble in to a regular form. For this research, the marble waste powder has directly been collected from the machine to avoid the effects of impurities. The physical properties of marble waste powder have been obtained in the laboratory and summarized in Table 3.6. Chemical compositions of marble waste powder are presented on Table 3.7.



Figure 3.4 Marble Wastes

Table 3.6 Physical properties of Marble waste powder

| Item No. | Description                          | Test result                     |      |
|----------|--------------------------------------|---------------------------------|------|
| 1        | Fineness ( $\text{cm}^2/\text{gm}$ ) | 2516.4                          |      |
| 2        | Specific gravity                     | 2.57                            |      |
| 3        | Normal consistency test              | Water to marble waste ratio (%) | 24.5 |
|          |                                      | Water (gm)                      | 73.5 |
|          |                                      | Penetration (mm)                | 11   |

Table 3.7 Chemical composition of marble waste powder

| Oxides                         | Percentage |
|--------------------------------|------------|
| CaO                            | 51.44      |
| SiO <sub>2</sub>               | 2.24       |
| Al <sub>2</sub> O <sub>3</sub> | 1.21       |
| K <sub>2</sub> O               | 1.32       |
| MgO                            | 0.94       |
| Fe <sub>2</sub> O <sub>3</sub> | <0.01      |
| Na <sub>2</sub> O              | <0.01      |
| MnO                            | <0.01      |
| P <sub>2</sub> O <sub>5</sub>  | 0.15       |
| TiO <sub>2</sub>               | 0.10       |
| H <sub>2</sub> O               | 0.33       |
| LOI                            | 41.33      |

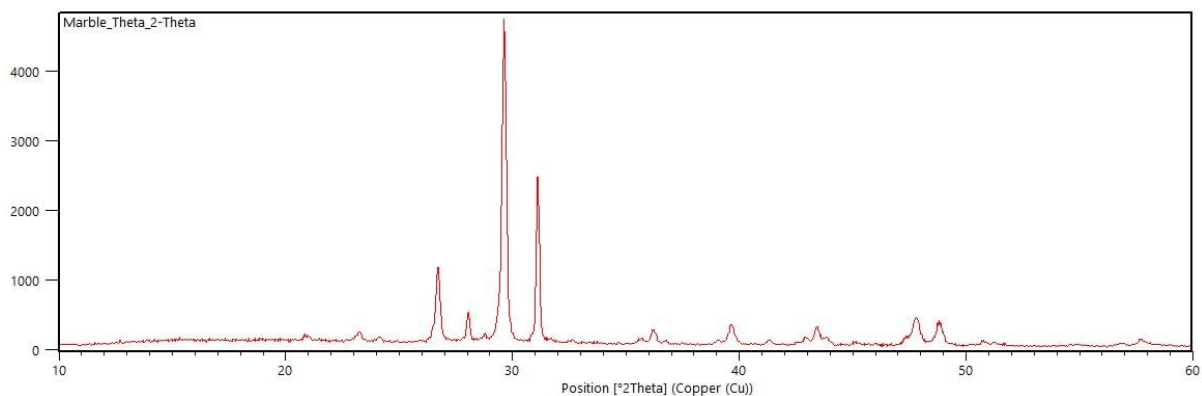


Figure 3.5 XRD pattern of Marble Waste Powder

The quantitative and qualitative determination of phase composition, polymorphic modification, state of crystallinity and other individual phase features are the potential uses of XRD power diffraction in the study of clinker and anhydrous cement. In the pattern of a typical Portland cement where peaks and phases are assigned, alite is normally so much predominant phase that its pattern tends to swamp other phases. The alite peaks overlaps that of all the stronger peaks of belite. As it can be observed in figure 3.5, some peaks are narrow that is where the intensity is higher. The narrow peaks indicate that the particles are in the proper order and that it contains a large number of small crystals having a definite geometrical shape. The results obtained has been analyzed using origin software and it is

attained that marble waste powder has 57.4% of crystallinity where it shows that 42.6% possess amorphous characteristics.

### 3.2.5 Ceramic Waste Powder

For this research the ceramic waste powder was collected from Tabor Ceramics, Hawassa. The physical properties of ceramic waste powder have been done in the laboratory and summarized in Table 3.8. The chemical compositions of ceramic waste powder are summarized in Table 3.9.



Figure 3.6 Ceramic Waste

Table 3.8 Physical properties of Ceramic waste powder

| Item No. | Description                          | Test result                      |     |
|----------|--------------------------------------|----------------------------------|-----|
| 1        | Fineness ( $\text{cm}^2/\text{gm}$ ) | 2046.93                          |     |
| 2        | Specific gravity                     | 2.5                              |     |
| 3        | Normal consistency test              | Water to ceramic waste ratio (%) | 30  |
|          |                                      | Water (gm)                       | 90  |
|          |                                      | Penetration (mm)                 | 9.5 |

Table 3.9 Chemical composition of ceramic waste powder

| Oxides                         | Percentage |
|--------------------------------|------------|
| CaO                            | 1.14       |
| SiO <sub>2</sub>               | 70.50      |
| Al <sub>2</sub> O <sub>3</sub> | 16.72      |
| K <sub>2</sub> O               | 3.46       |
| MgO                            | 3.72       |
| Fe <sub>2</sub> O <sub>3</sub> | 1.22       |
| Na <sub>2</sub> O              | 1.42       |
| MnO                            | <0.01      |
| P <sub>2</sub> O <sub>5</sub>  | 0.17       |
| TiO <sub>2</sub>               | 0.16       |
| H <sub>2</sub> O               | 0.49       |
| LOI                            | 1.45       |

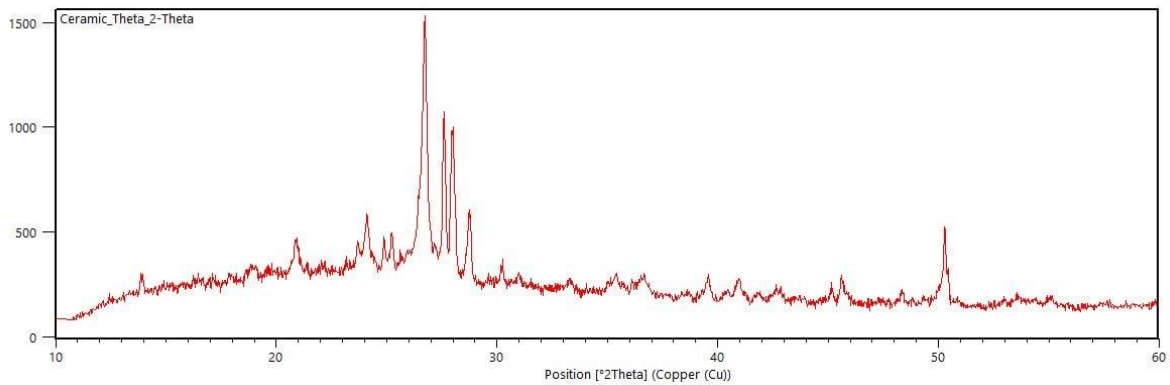


Figure 3.7 XRD pattern of Ceramic Waste Powder

As it can be observed from Figure 3.7, the intensities of most of the points in the ceramic waste powder pattern are not at one point rather they are diffused. This indicates that the powder consists of particles with irregular shape. The results obtained has been analyzed using origin software and it is also obtained that the crystallinity of ceramic waste powder is 42.73% and the rest 57.27% indicate amorphous properties. This shows that most of its properties are amorphous.

### 3.3 Methods

This section elaborates the methods used in achieving the objectives of the research.

#### 3.3.1 Mix design

The mix design is accomplished as per ACI 211.1-91 standard procedures [22]. The mix design is specified to concrete C-25. The quantity of each ingredient summarized in Table 3.10. Detailed calculation is presented in Appendix F.

Table 3.10 Quantity of Materials Required for C-25 concrete

| <b>Quantities in kg/m<sup>3</sup></b> |               |             |                         |              |               |                |
|---------------------------------------|---------------|-------------|-------------------------|--------------|---------------|----------------|
| <b>Mix No.</b>                        | <b>Cement</b> | <b>Sand</b> | <b>Coarse aggregate</b> | <b>Water</b> | <b>Marble</b> | <b>Ceramic</b> |
| 1                                     | 316.4         | 718.99      | 1151.61                 | 191.72       | 0             | 0              |
| 2                                     | 292.67        | 718.99      | 1151.61                 | 191.72       | 15.82         | 7.91           |
| 3                                     | 284.76        | 718.99      | 1151.61                 | 191.72       | 15.82         | 15.82          |
| 4                                     | 284.76        | 718.99      | 1151.61                 | 191.72       | 23.73         | 7.91           |
| 5                                     | 276.85        | 718.99      | 1151.61                 | 191.72       | 23.73         | 15.82          |
| 6                                     | 276.85        | 718.99      | 1151.61                 | 191.72       | 31.64         | 7.91           |
| 7                                     | 268.94        | 718.99      | 1151.61                 | 191.72       | 31.64         | 15.82          |
| 8                                     | 300.58        | 718.99      | 1151.61                 | 191.72       | 15.82         | 0              |
| 9                                     | 284.76        | 718.99      | 1151.61                 | 191.72       | 31.64         | 0              |
| 10                                    | 268.94        | 718.99      | 1151.61                 | 191.72       | 47.46         | 0              |
| 11                                    | 308.49        | 718.99      | 1151.61                 | 191.72       | 0             | 7.91           |
| 12                                    | 300.58        | 718.99      | 1151.61                 | 191.72       | 0             | 15.82          |
| 13                                    | 292.67        | 718.99      | 1151.61                 | 191.72       | 0             | 23.73          |

Table 3. 11 Mixture Designations

| Mix No. | Percentage |        |         |
|---------|------------|--------|---------|
|         | Cement     | Marble | Ceramic |
| M-1     | 100        | 0      | 0       |
| M-2     | 92.5       | 5      | 2.5     |
| M-3     | 90         | 5      | 5       |
| M-4     | 90         | 7.5    | 2.5     |
| M-5     | 87.5       | 7.5    | 5       |
| M-6     | 87.5       | 10     | 2.5     |
| M-7     | 85         | 10     | 5       |
| M-8     | 95         | 5      | 0       |
| M-9     | 90         | 10     | 0       |
| M-10    | 85         | 15     | 0       |
| M-11    | 97.5       | 0      | 2.5     |
| M-12    | 95         | 0      | 5       |
| M-13    | 92.5       | 0      | 7.5     |

### 3.3.2 Concrete mix

All the concrete mixes were done in the laboratory by using the mixer shown in Figure 3.9 with the ingredients ready to be mixed. The standards in ASTM C192 [23] were used in making and curing the concrete test specimens in the laboratory. At first the coarse aggregate was added to the mixer followed by cement and then the fine aggregate. The materials were dry blended and two-thirds of the water measured was added and the mixing continued for another minute. The remaining water added and the ingredients were thoroughly mixed until uniform consistency was achieved.



Figure 3.8 Marble and Ceramic powders ready for mix



Figure 3.9 Mixer and Ingredients ready for mix

The slump of every freshly mixed concrete was held to check the workability of concrete and was measured according to ASTM C-143 [24].



Figure 3.10 Measuring slump of fresh concrete mix

Before casted to the molds, the freshly mixed concrete was tested for its workability in a slump test cone being compacted per batch in three rounds. The inner surfaces of the molds prepared were smeared with machine oil as shown in Figure 3.11. Finally, the concrete was poured into the prepared molds and a vibrator was used to force the trapped air out of the mixture leaving the final product a more compact and leveled. The concrete specimens were taken out of their molds after 24 hours and put in a water tank for curing until their due date as shown in Figure 3.13.



Figure 3.11 Oil paint concrete molds



Figure 3.12 Concrete Specimen after cast



Figure 3.13 Concrete Specimens in water tank for Curing

### **3.3.3 Testing methods**

Mechanical properties of concrete can be tested using different testing methods. In this research, chemical shrinkage, compressive strength, splitting tensile strength and flexural strength tests have been performed.

#### **3.3.3.1 Chemical shrinkage test**

The internal volume change of hydraulic cement paste that results from the hydration of cementitious materials is known as chemical shrinkage and which is measured by the test

method specified on ASTM C 1608-07 [28]. A total of 21 cement paste samples were made with different partial replacements. The chemical shrinkage is computed as the measured mL of absorbed water per gram of cement in the paste specimen where the cement hydration products occupy less physical volume than the reactants.

The mass of cement powder in the vial is given by:

$$M_{\text{cement}} = \frac{M(\text{vial}+\text{paste}) - M_{\text{vial empty}}}{1+w/c} \quad (3.3)$$

Where,  $M_{\text{cement}}$  = mass of cement in the vial (g)

$M_{\text{vial}+\text{paste}}$  = mass of the vial glass with the added cement paste (g)

$M_{\text{vial}}$  = mass of glass vial (g)

w/c = water to cement ratio by mass of prepared paste (g)

The chemical shrinkage per unit mass of cement at time t is computed as:

$$CS(t) = \frac{[h(t) - h(60\text{min})]}{M_{\text{cement}}} \quad (3.4)$$

Where,  $CS(t)$  = chemical shrinkage at time t (mL/g)

$h(t)$  = water level in capillary tube at time t (mL)



Figure 3.14 Apparatus preparation for chemical shrinkage test

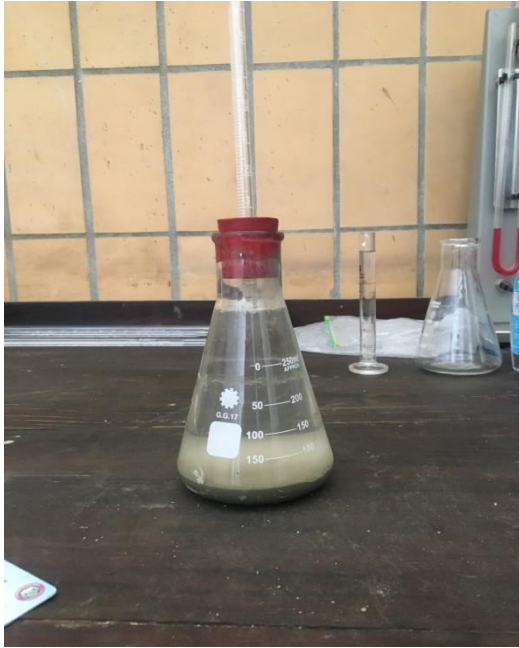


Figure 3.15 Chemical shrinkage test set up



Figure 3.16 Preparation of de-aerated water

### 3.3.3.2 Compressive Strength Test

When the curing time of the concrete specimens were reached, they were taken out of the curing water tank and were surface dried before their test. The test was held according to ASTM C39 [25]. The specimens were first weighted and tested at seven and twenty-eight days with the Universal Testing machine. The load was applied gradually with the rate of loading of 0.28 MPa/sec till the failure stage is reached and capacity of 3000KN. For each mix, three cubes were tested for the compressive strength test of seven and twenty-eight days of concrete age for the blended effects of the cement with marble waste powder and ceramic waste powder. And three samples for each mix in checking the effects of marble and ceramic waste powders individually for a twenty-eight concrete age. For this test 60 cube samples were casted on cube with dimensions of 150mm×150mm×150mm. Figure 3.17 shows the compressive strength testing machine and the setup ready for the test. The detailed results of compressive strength test are provided in appendix G.



Figure 3.17 Compressive Strength Test Setup

### 3.3.3.3 Splitting Tensile Strength Test

The splitting tensile strength test is conducted to determine the splitting tensile strength of a concrete. The splitting tensile strength method consists of applying a diametric compressive force along the length of a cylindrical concrete specimen at a rate of 689 to 1380kPa/min until failure occurs (ASTM C-496-71) [26]. For this test 60-cylinder samples where three samples for each mix were prepared with a dimension of a cylinder 150mm in diameter and

300mm height. The samples were tested for both 7<sup>th</sup> and 28<sup>th</sup> days. The following equation shows the splitting tensile.

$$T = 2P/\pi ld \quad (3.1)$$

Where,

T= splitting tensile strength, psi (KPa)

P= maximum applied load (KN)

l= length of cylindrical specimen (m)

d = diameter of cylindrical specimen (m)



Figure 3.18 Splitting Tensile Strength Test Setup

#### 3.3.3.4 Flexural Strength Test

This test aims in determining the tensile strength of the concrete. It is also known as bend strength or modulus of rupture. The test was held according to ASTM C 78 – 94 [27]. The flexural strength represents the highest stress experienced within the material at its moment of yield. The concrete was casted on a mold of a beam member having dimensions of 100 mm in width, 100 mm in height and 500 mm in length. A total of 21 samples were casted. If the fracture initiates in the tension surface within the middle third of the span length, calculate the modulus of rupture as follows:

$$R = PL/bd^2$$

Where:

R = modulus of rupture, psi, or MPa,

P = maximum applied load indicated by the testing machine, lbf, or N,

L = span length, in., or mm,

b = average width of specimen, in., or mm, at the fracture, and

d = average depth of specimen, in., or mm, at the fracture



Figure 3.19 Flexural Strength Test Setup

## 4. RESULTS AND DISCUSSIONS

### 4.1 Introduction

This portion discuss about the results obtained in the laboratory of the tests occurred to investigate the properties of fresh and hardened concrete by partially replacing cement with marble and ceramic waste powder using different replacement. The samples were compared with both the control mixes and with the standard to drive on conclusions. In this section of the research, the results obtained from slump test, compressive strength test, splitting tensile strength test, flexural strength test and early-stage shrinkage test done on normal strength concrete is addressed.

### 4.2 Fresh Concrete Properties

#### 4.2.1 Slump test

A slump test is performed to check the workability of a fresh concrete. A total of thirteen mixes were designed with varying level of marble and ceramic waste powders replacement. Figure 4.1 shows the results obtained in the slump test.

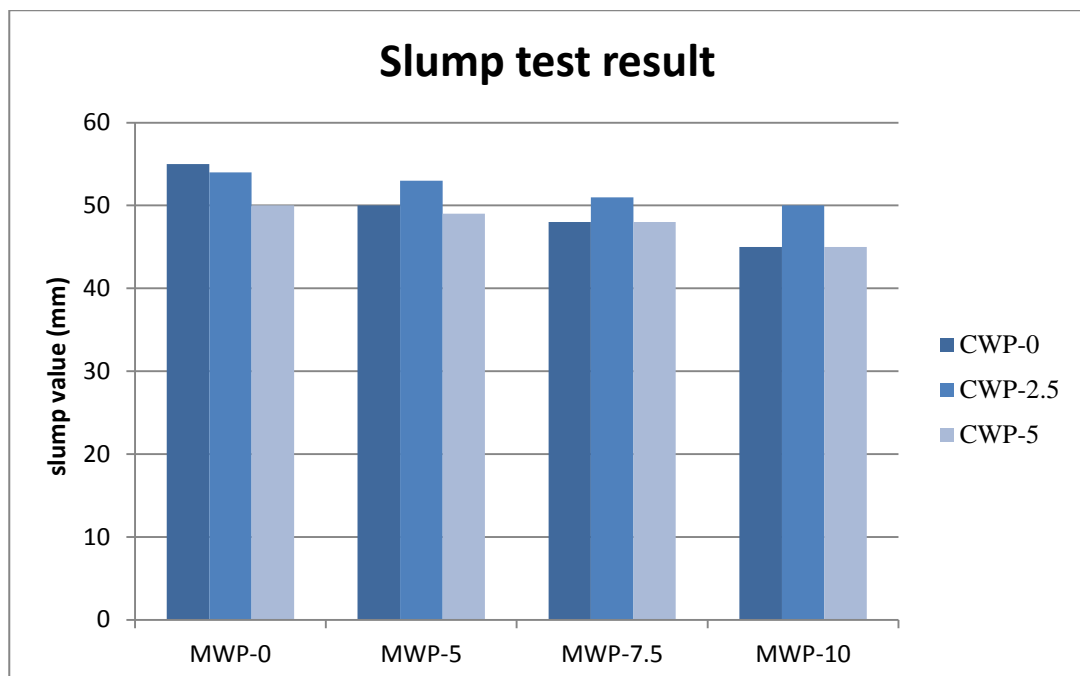


Figure 4.1 The observed slump for concrete mix

As indicated in Figure 4.1, loss of workability was noticed with increasing the replacement of cement with marble and ceramic waste powders. This indicates that as the slump decreased, the workability of the concrete also decreased.

#### 4.2.2 Chemical shrinkage of concrete

Chemical shrinkage of concrete test is one of the methods to check the early volume changes of concrete. Chemical shrinkage for a total of seven mixes has been performed. For the first 8 hours with an interval of 30 minutes, measurement of the capillary tube height was taken. A mean value of chemical shrinkage for three pastes at time of 24 hours was calculated for each mix. The thickness of the cement paste was taken to be 7.5 mm to allow the water penetration to the whole depth of the cast all specimens all the way. Figure 4.2 shows the results obtained for chemical shrinkage of an ordinary Portland cement which is used as a reference (M-1) and results of chemical shrinkage for cement blended with marble and ceramic waste powders (M-2, M-3, M-4, M-5, M-6 and M-7) are shown.

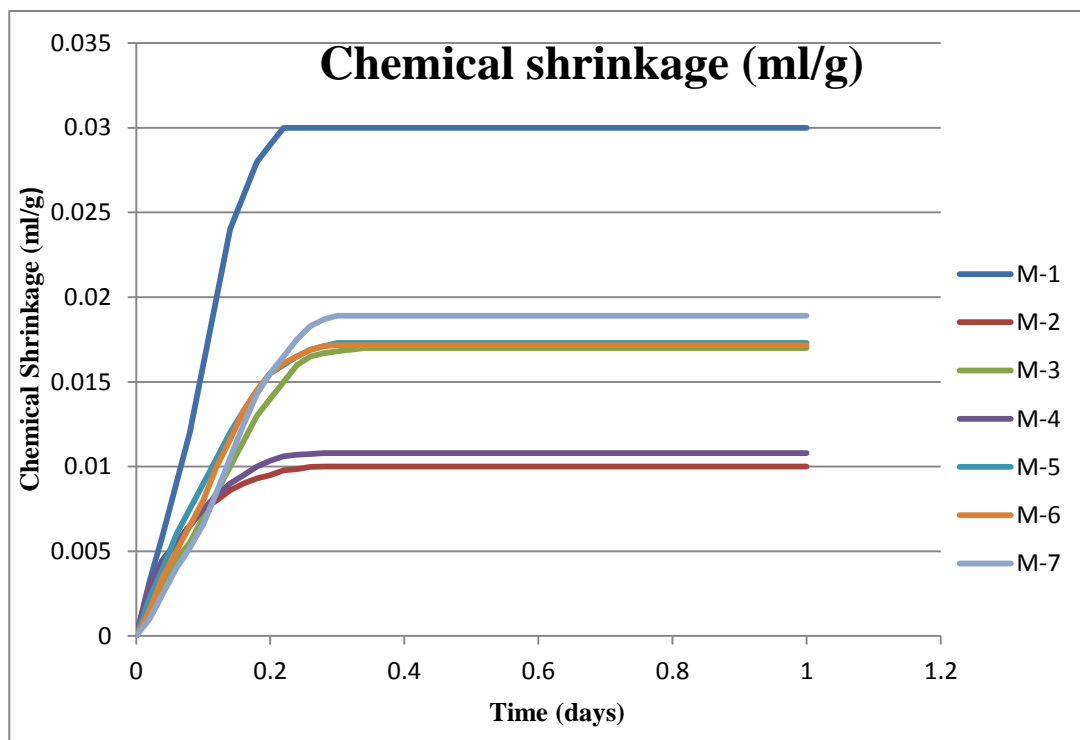


Figure 4.2 Chemical Shrinkage for all mixes

As observed in figure 4.2, the average chemical shrinkage of OPC is 0.03 ml/g at 24 hours after the preparation of the cement paste. The result became constant after the initial setting time of cement at about 4 hours after the paste was prepared but till then it has a gradual

increase of chemical shrinkage. The gradual increase of chemical shrinkage is due to the hydration degree. Chemical shrinkage is proportional to the degree of hydration in which the higher is the degree of hydration then the higher is specific chemical shrinkage. The result obtained for chemical shrinkage of mix-2 is 0.01 ml/g for the time interval of 24 hours. This value has shown a reduction of chemical shrinkage by 0.02 ml/g from the reference value. This shows that a lesser early age volume reduction than the reference cement paste. The chemical shrinkage obtained for M-3 is 0.017 ml/g that shows a reduction of 0.013 ml/g from the reference value. This mix has ceramic waste powder about 5% of the paste which adds more pozzolanic effect to the paste regarding initial setting time. The result shows that it attains a constant value after 7 hours of the paste preparation. The chemical shrinkage of M-4 is 0.0108 ml/g. This value has shown a reduction of 0.0192 ml/g from the reference value. The result has also shown a gradual increment in chemical shrinkage until the initial setting time of the paste containing cement blended with marble and ceramic waste powders has reached. This shows that a lesser early age volume reduction than the reference cement paste. The result attained for M-5 is 0.0173 ml/g which has a reduction of 0.0127 ml/g from the reference value. This mix has ceramic waste powder about 5% of the paste which adds more pozzolanic effect to the paste regarding initial setting time. The result shows that it attains a constant value after nearly about 7 hours of the paste preparation. The result attained for M-6 of chemical shrinkage which is 0.01716 ml/g for the test performed with in 24 hours' time interval. The result has shown a reduction of 0.01284 ml/g from the reference value. This indicates that the mix has a lesser effect in early age cracking than the reference mix. The chemical shrinkage for M-7 is 0.0189 ml/g that shows a reduction of 0.0111 ml/g from the reference value. The result obtained shows a gradual increase in chemical shrinkage till it reached the initial setting time of cement and attained a constant value after that. This mix has ceramic waste powder about 5% of the paste which adds more pozzolanic effect to the paste regarding initial setting time. The result shows that it attains a constant value after 7 hours of the paste preparation.

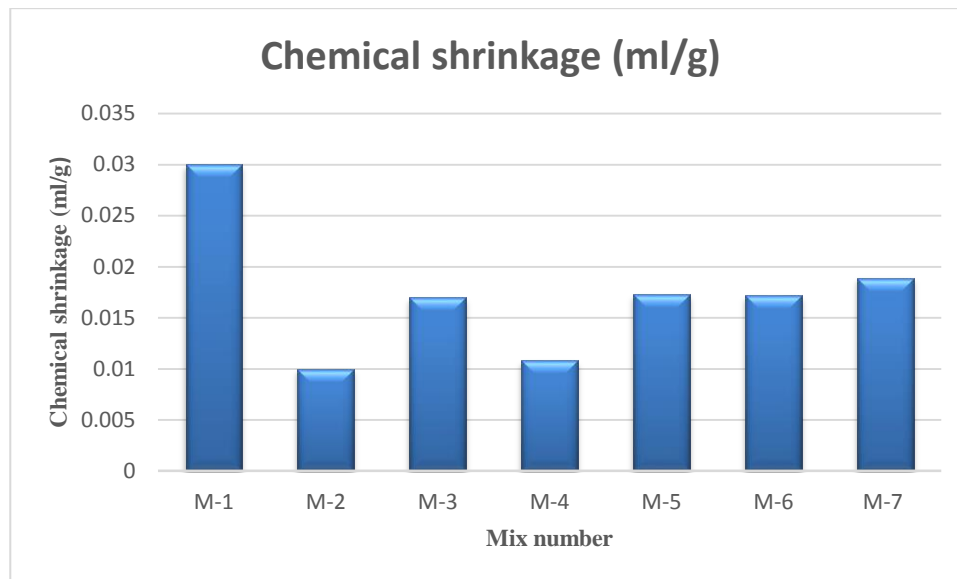


Figure 4.3 Chemical Shrinkage of control mix versus replacement mixes

Chemical shrinkage is the reason behind early age cracking and the main cause of autogenous shrinkage. The chemical shrinkage tests performed for all mixes resulted in lesser value from the reference mix. This indicates that early age cracking and autogenous shrinkage have a reduced opportunity of occurring in all other mixes compared to OPC.

### 4.3 Hardened Concrete Properties

To investigate the mechanical properties of normal strength of concrete compressive and splitting tensile strength tests for 7<sup>th</sup> and 28<sup>th</sup> days are performed. Additionally, flexural strength test at 28<sup>th</sup> day of concrete age.

#### 4.3.1 Compressive Strength of Concrete

The compressive strength of concrete was tested and analyzed. A mean value of three specimens was taken for each replacement of cement with marble and ceramic waste powders. The samples were tested after being cured for both 7 and 28 days. The detailed results of the compressive strength test are provided in Appendix G. The average results are clearly described in Figure 4.4.

Compressive strengths of all the concrete samples are kept at the same level to only study the effect of adding marble and ceramic waste powders into cement using different replacement ratios. In order to check the individual effects of the marble and ceramic waste powders being blended with cement on a normal strength concrete, six different types of mixes were

conducted. The mean results are obtained after curing the samples for 28 days. Table 4.3 summarizes the results obtained in checking the effects of marble and ceramic waste powders individually on the concrete.

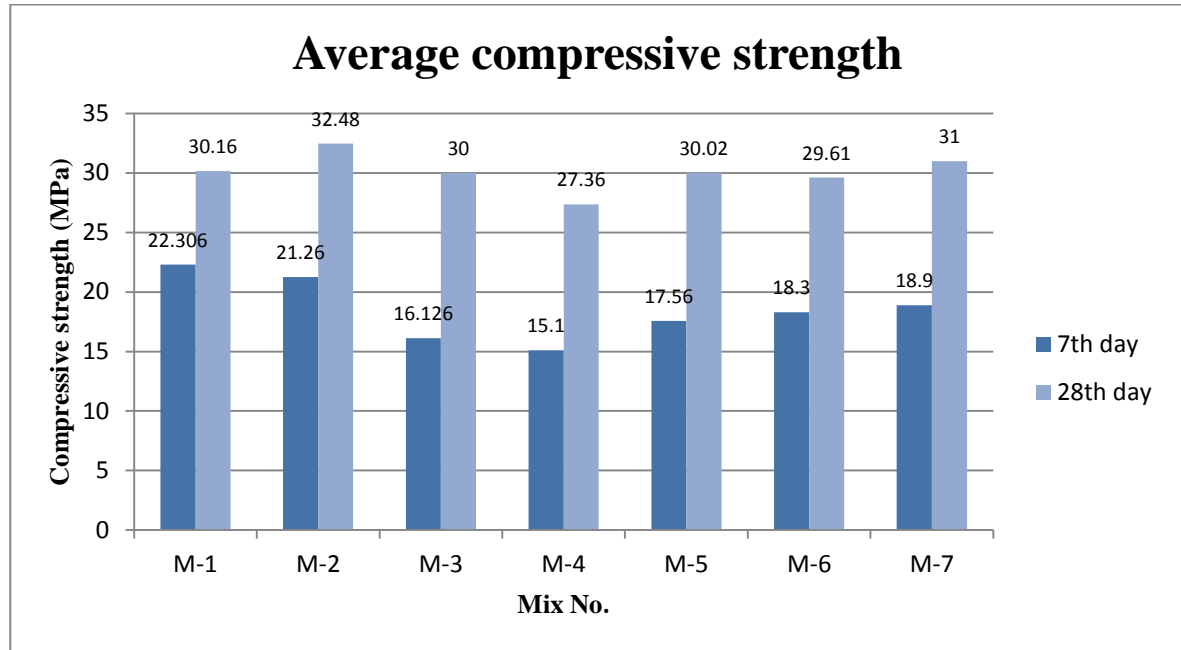


Figure 4.4 Average compressive strength of concrete

As it can be observed from figure 4.4, at early curing age, reduction in compressive strength has been attained. This could be due to the fact that pozzolan only acts as filler and does not undergo the pozzolanic reaction at early curing ages and the preventive growth of C-S-H gel affected by components in ground ceramic powder.

The compressive strength of concrete obtained at 28 days showed an increment in M-2 and M-7 by 7.7% and 2.73% respectively. As it can be observed from the results, curing time enhances the compressive strength of concrete. Compressive strength may be gained to the fact that the active  $\text{SiO}_2$  in waste ceramic powder can react to  $\text{Ca}(\text{OH})_2$  in concrete resulting in secondary calcium silicate hydrate and make it stable chemically and dense structurally [29]. An increase in compressive strength at later ages is obtained due to that CWP can react with released CH. Waste marble powder usage show a filler effect that can be assumed as ultrafine aggregates filling voids in concrete, reduces the porosity in concrete matrix physically and has an important binding property developed by hydration of calcite and  $\text{C}_3\text{A}$  chemically [30].

As it can be observed in Figure 4.4, decrement in average compressive strength on M-3, M-4, M-5 and M-6 by 0.53%, 9.28%, 0.46% and 1.82% respectively from the reference Portland cement. This could be resulted due to the fact that ceramic waste powder has very limited immediate hydraulic reaction due to its low CaO. A slight decrease in compressive strength is observed due to the reduction in cementing materials ( $C_3S$  and  $C_2S$ ) which are responsible for concrete strength.

However, all the compressive strength results meet the minimum requirement of the compressive strength of grade C-25.

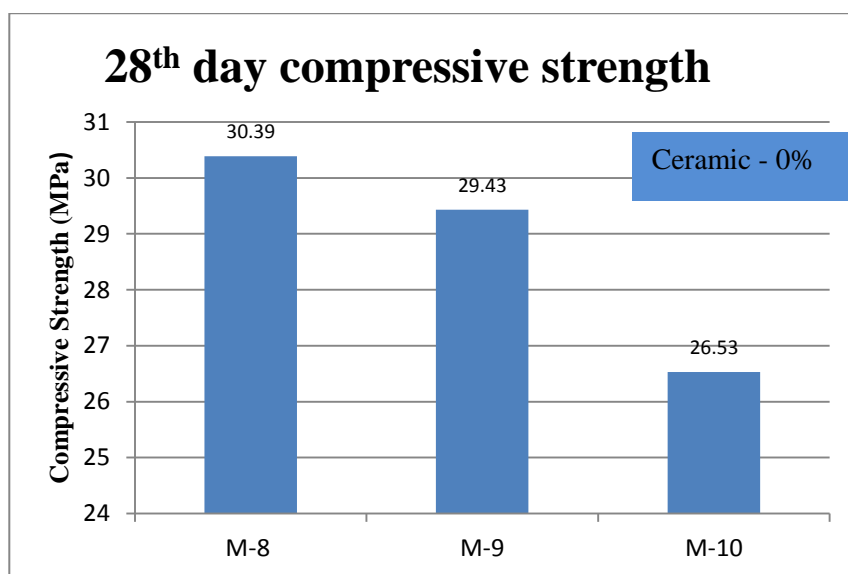


Figure 4.5 Average compressive strength of concrete

From figure 4.5 the compressive strength of the concrete decrease with the increase of marble waste powder where fixing the value of ceramic to zero. As it can be observed from the 28<sup>th</sup> day compressive strength for M-8 increased by 0.76% whereas, M-9 and M-10 decreased in compressive strength by 2.42% and 12% respectively. This showed that going beyond 10 % for marble waste powder does not have an essential effect being blended with cement and ceramic waste powder in compressive strength of concrete.

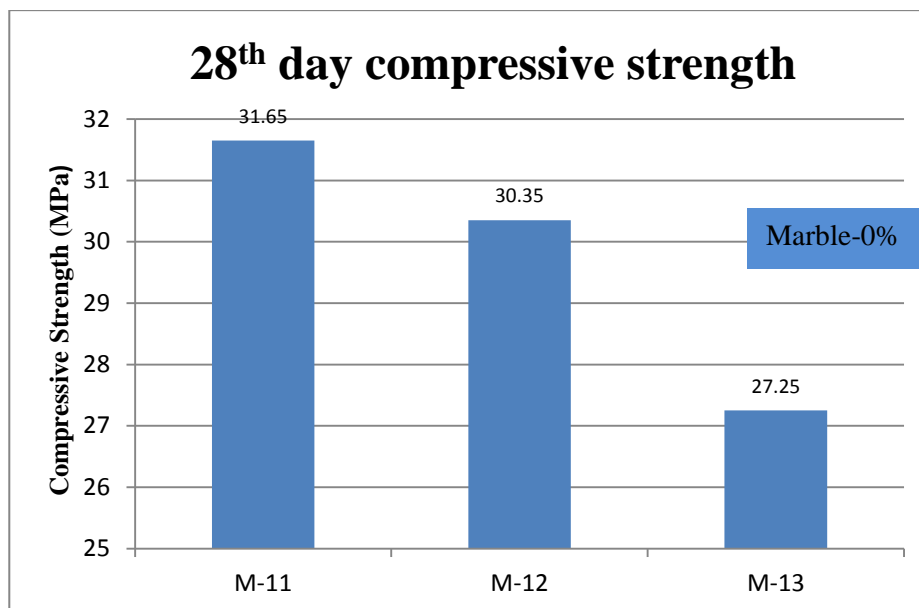


Figure 4.6 Average compressive strength of concrete

From Figure 4.6 the compressive strength of the concrete decrease with the increase of ceramic waste powder where fixing the value of marble to zero. As it can be observed from the 28<sup>th</sup> day compressive strength for M-11 and M-12 increment in compressive strength by 4.94% and 0.63% respectively whereas, M-13 decreased in compressive strength by 9.65%. This showed that going beyond 5% for ceramic waste powder when blending it with cement and marble waste powder does not have an essential effect on the compressive strength of concrete.

#### 4.3.2 Splitting tensile strength of concrete

A mean value of three specimens was taken for each replacement of cement with marble and ceramic waste powders for seven different mixes with different replacement ratio. The samples were tested after being cured for both 7 and 28 days. Figure 4.7 represents the average splitting tensile strength of concrete. In order to check the individual effects on a splitting tensile strength of the marble and ceramic waste powders being blended with cement on a normal strength concrete, six different types of mixes were conducted. The mean results are obtained after curing the samples for 28 days and represented on Figure 4.8 and Figure 4.9.

From figure 4.7 the splitting tensile strength of concrete obtained an increment in M-2 and M-3 by 23.95% and 5.68% respectively. An optimal value of splitting tensile strength has been obtained on M-2. As it can be observed decrement in average splitting strength on M-4, M-5, M-6 and M-7 by 17%, 4.49%, 26.9% and 20.95% respectively.

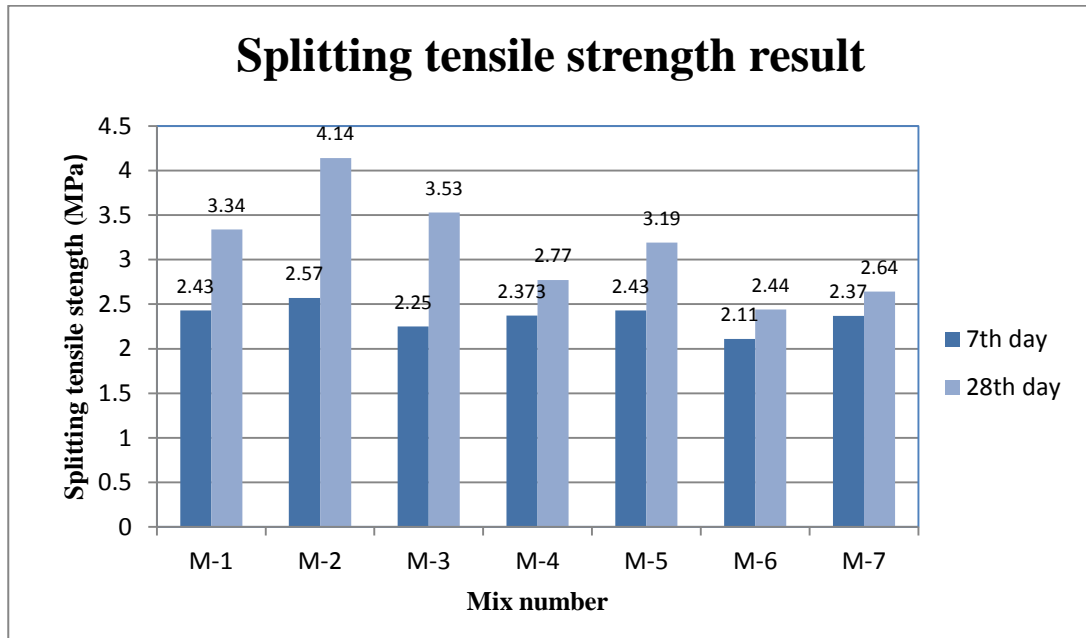


Figure 4.7 Average splitting tensile strength of concrete

However, the splitting tensile strength results obtained for all mixes satisfy the minimum required value for the attained compressive strength for C-25 concrete grade.

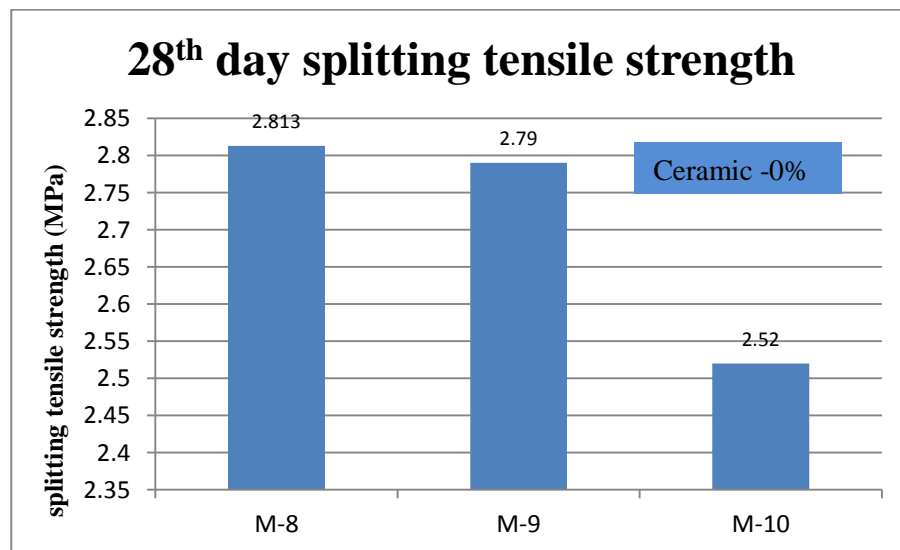


Figure 4.8 Average splitting tensile strength of concrete

From Figure 4.8 the splitting strength of the concrete decrease with the increase of marble waste powder where fixing the value of ceramic to zero. Decrement in splitting tensile strength by 15.7%, 16.46% and 24.55% of the 28<sup>th</sup> day splitting tensile strength for M-8, M-9, and M-10 is observed respectively. This showed that increasing the value for marble more than 10%, does not enhance the splitting tensile strength.

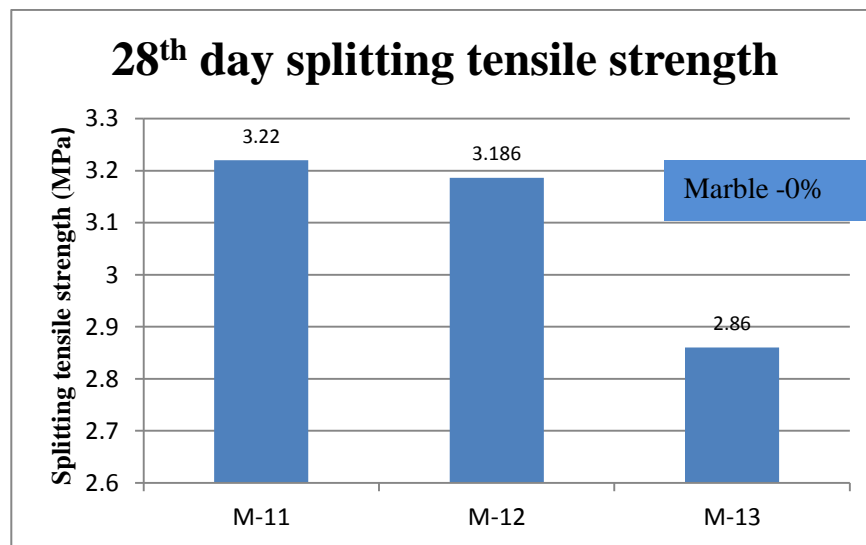


Figure 4.9 Average splitting tensile strength of concrete

From Table 4.9 the splitting strength of the concrete decrease with the increase of ceramic waste powder where fixing the value of marble to zero. The 28<sup>th</sup> day splitting tensile strength for M-11, M-12, and M-13, decrement in splitting tensile strength by 3.59%, 4.61% and 14.37% respectively is observed. The results attained show that increasing the value for ceramic waste powder does not enhance the splitting tensile strength.

#### 4.3.3 Flexural strength test analysis

A mean value of three specimens was taken for each replacement of cement with marble and ceramic waste powders for seven different mixes with different replacement ratio. The samples were tested after being cured for 28 days. Figure 4.10 presents the average results obtained from flexural strength of concrete.

As it can be seen in the figure, the flexural strength of the concrete obtained an optimal value at M-4 showing an increment in flexural strength by 19.84% and an increment in flexural strength by 3.56% at M-3. The flexural strength at 28<sup>th</sup> days for M-2, M-5, M-6 and M-7 have a decrement of 15.5 %, 18 %, 22.4% and 33% respectively.

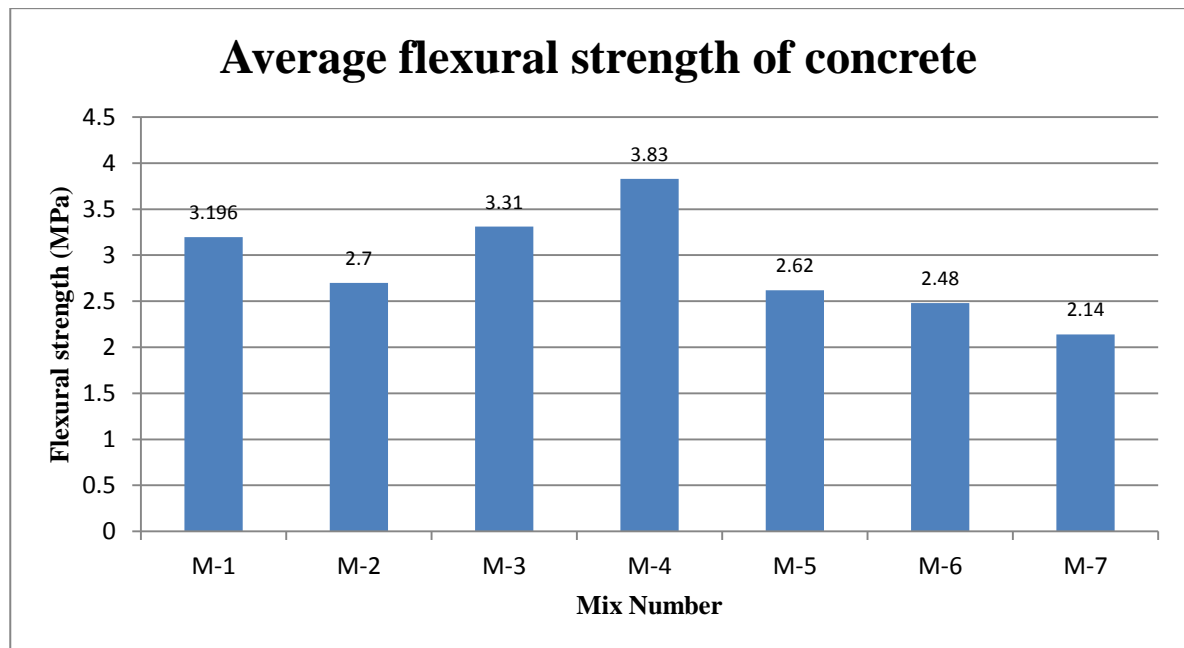


Figure 4.10 Average flexural strength of concrete

In order to relate compressive strength and flexural strength of concrete, several empirical equations have been suggested. Table 4.1 summarizes the empirical equations suggested by ACI Committee 318, 2005[38], Indian code (IS, 2000) [39] and European code (CEN, 2002) [40]. Most of these equations are of the power equation type.

$$f_r = b f_c^n$$

Where  $f_r$  is flexural tensile strength,  $f_c$  is the compressive strength of the concrete.  $b$  and  $n$  are correlation coefficients.

Table 4. 1 Empirical equations suggested by codes

| Codes | Equations                 |
|-------|---------------------------|
| ACI   | $f_r = 0.517 * f_c^{0.5}$ |
| ES.EN | $f_r = 0.626 * f_c^{0.5}$ |
| IS    | $f_r = 0.342 * f_c^{2/3}$ |

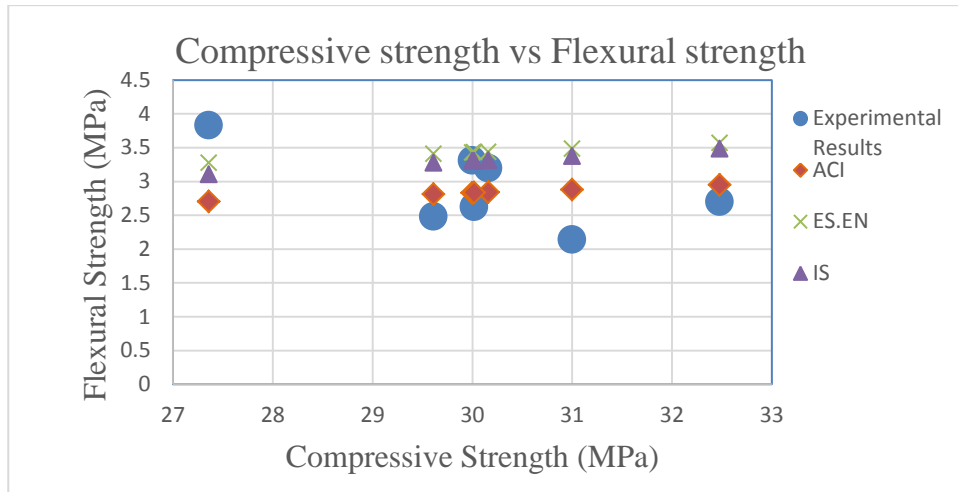


Figure 4.11 Compressive strength vs Flexural strength

As it can be perceived from Figure 4.11, the results obtained for flexural strength in relation with the compressive strength of concrete using three different codes show almost close results with that of the actual flexural strength of concrete attained in doing the experiments.

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

Based on the experimental investigation results the following conclusions are drawn:

1. For the tests conducted in slump and chemical shrinkage:
  - The workability of concrete decreases with an increase of replacement percentage of marble and ceramic waste powders.
  - All of the mixes do not possess an early age cracking due to the result obtained from the chemical shrinkage test.
2. For the tests conducted for compressive and splitting tensile strength tests: even if the increment is small, an optimal mix has been obtained while taking marble 5% and ceramic 2.5%.
3. For the tests conducted for flexural strength tests: the mix prepared taking marble 7.5% and ceramic 2.5% has shown an increment of 19.84% from the reference mix.
4. M-3 which is 10% replacement of cement is in acceptable range in all of the requirements of concrete.
5. For resting members where cracking is not the main concern such as foundation and machine resting members, M-7 that is 15% replacement of cement is certain. The attained compressive strength for this mix is 31 MPa which shows an increment of 2.73% from the reference value.
6. According to section 26.12 of ACI 318-19, all of the results obtained for compressive strength, splitting tensile strength and flexural strength of concrete are in acceptable range regarding the standard requirements for each test of concrete.

## **5.2 Recommendations**

The following areas of studies shall be investigated regarding the topic of research:

- The effect of durability where cement is blended with marble and ceramic waste powders.
- Further study is recommended on checking the effect of adding fibers for those mixes that has attained less flexural strength results as compared to the reference mix.

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**APPENDIX**

Appendix A- Tests for Cement

Appendix B- Tests for Fine Aggregate

Appendix C- Tests for Coarse Aggregate

Appendix D- Tests for Marble Waste Powder

Appendix E- Tests for Ceramic Waste Powder

Appendix F- Mix Design

Appendix G-Test Results for Compressive, Splitting Tensile and Flexural Strength of  
Concrete

Appendix H- Sample calculation and results for Chemical Shrinkage of Concrete

Appendix I - Pictures

**Appendix A- Tests for Cement**

| Item No. | Description                            | Test result                |     |
|----------|--|----------------------------|-----|
| 1        | Fineness of cement                     | 2.83%                      |     |
| 2        | Specific gravity (gm/cm <sup>3</sup> ) | 3.15                       |     |
| 3        | Cement consistency test                | Water to cement ratio (%)  | 27  |
|          |  | Water (gm)                 | 135 |
|          |  | Penetration (mm)           | 10  |
| 4        | Setting time                           | Initial setting time (min) | 75  |
|          |  | Final setting time (min)   | 255 |

**Appendix B- Tests for Fine Aggregate**

**B-1: Sieve analysis results of fine aggregate**

| Sieve size(m m) | Weight of sieve (gm) | Weight retained (gm) | Percentage retained (%) | Cumulative coarser (%) | Cumulative passing (%) | ASTM C33 standard passing range (%) |
|-----------------|----------------------|----------------------|-------------------------|------------------------|------------------------|-------------------------------------|
| 9.75            | 445                  | 0.2                  | 0.04                    | 0.04                   | 100                    | 100                                 |
| 4.75            | 426                  | 0.3                  | 0.06                    | 0.1                    | 99.9                   | 95-100                              |
| 2.36            | 387.6                | 27.9                 | 5.58                    | 5.68                   | 94.32                  | 80-100                              |
| 1.18            | 372.5                | 70.9                 | 14.18                   | 19.86                  | 80.14                  | 50-85                               |
| 0.6             | 312.5                | 143.8                | 28.76                   | 48.62                  | 51.38                  | 25-60                               |
| 0.3             | 279.6                | 188.8                | 37.76                   | 86.38                  | 13.62                  | 5-30                                |
| 0.15            | 291.8                | 56.2                 | 11.24                   | 97.62                  | 2.38                   | 0-10                                |
| pan             | 336.1                | 8.3                  | 1.66                    | 99.28                  | 0.72                   | 0                                   |

FM (Fineness modulus) =  $\text{Cumulative coarser}(\%) / 100$

$$F.M = \frac{258.3}{100} = 2.583 \approx 2.6$$

**B-2: Moisture content of the fine aggregate**

Weight of original sample= 500g

Weight of original Sample+ weight of container = 535g

Weight of container = 35g

Weight of oven-dry sample = 492.5g

Moisture content

$$\begin{aligned} &= \frac{\text{original sample weight} - \text{weight of oven dry sample}}{\text{weight of oven dry weight}} * 100\% \\ &= \frac{(500 - 492.5)}{492.5} * 100 \end{aligned}$$

Moisture content = 1.523%

### **B-3: Unit weight of fine aggregate**

Weight of measure + content = 15.395Kg

Weight of measure = 4.66 Kg

Net weight of aggregate = (weight of measure + content) – weight of measure

$$= 15.395 - 4.66 = 10.735Kg$$

Volume of measure =  $\frac{\pi d^2}{4} * h$

d=0.205m and h=0.217m

$$\text{Volume of measure} = \pi * \frac{0.205^2}{4} * 0.217 = 0.0072m^3$$

Unit weight of fine aggregate =  $\frac{\text{net weight of aggregate}}{\text{volume of measure}} = \frac{10.735Kg}{0.0072m^3} = 1490.97 Kg/m^3$

### **B-4: Specific gravity and absorption capacity for fine aggregate**

Weight of original sample = 500g

Weight of water + weight of pycnometer = 706.4g

Weight of sample + water + pycnometer = 1007.1g

Weight of oven dry sample = 488.9g

$$\text{Bulk specific gravity} = \frac{488.9}{706.4+500-1007.1} = 2.453 g/cm^3$$

$$\text{Bulk specific gravity (SSD basis)} = \frac{500}{706.4+500-1007.1} = 2.51 \text{ g/cm}^3$$

$$\text{Apparent specific gravity} = \frac{488.9}{706.4+488.9-1007.1} = 2.597 \text{ g/cm}^3$$

$$\text{Absorption capacity} = \frac{500-488.9}{488.9} * 100 = 2.27\%$$

#### **B-5: Silt content of the fine aggregate**

$$\text{Silt content (\%)} = \frac{\text{amount of silt content}}{\text{clean sand}} * 100$$

$$\text{Silt content (\%)} = \frac{0.4\text{mm}}{30\text{mm}} * 100\% = 1.33\%$$

### **Appendix C- Tests for Coarse Aggregate**

#### **C-1: Sieve analysis results of coarse aggregate a**

| Sieve size(mm) | Weight of sieve (gm) | Retained weight (Kg) | Percentage retained (%) | Cumulative coarser (%) | Cumulative passing (%) | ASTM C33 standard passing range (%) |
|----------------|----------------------|----------------------|-------------------------|------------------------|------------------------|-------------------------------------|
| 25             | 1204.2               | 0                    | 0                       | 0                      | 100                    | 95-100                              |
| 19             | 1381.2               | 131.2                | 6.56                    | 6.56                   | 93.44                  | -                                   |
| 12.5           | 1154.6               | 882                  | 44.1                    | 50.66                  | 49.34                  | 25-60                               |
| 9.5            | 1157.4               | 736.2                | 36.81                   | 87.47                  | 12.53                  | -                                   |
| 4.75           | 1168.8               | 247                  | 12.35                   | 99.82                  | 0.18                   | 0-10                                |
| pan            | 733.4                | 3.6                  | 0.18                    | 100                    | 0                      | 0                                   |

To determine the fineness modulus of coarse aggregate the values of intermediate sieves are not included. The following table shows the fineness modulus of coarse aggregate considering 38.1mm, 19mm, 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, and 0.15 mm sieve sizes.

| Sieve size (mm) | Cumulative retained (%) |
|-----------------|-------------------------|
| 38.1            | 0                       |
| 19              | 6.56                    |
| 9.5             | 87.47                   |
| 4.75            | 99.82                   |
| 2.36            | 100                     |
| 1.18            | 100                     |
| 0.6             | 100                     |
| 0.3             | 100                     |
| 0.15            | 100                     |
| Total           | 693.85                  |

FM (Fineness modulus) =  $\Sigma \text{cumulative caorser}(\%) / 100$

$$F.M = 693.85/100 = 6.94$$

### C-2: Moisture content of the coarse aggregate

Weight of original sample = 2000g

Weight of oven-dry sample = 1960.207g

Moisture content

$$= \frac{\text{original sample weight} - \text{oven dry weight}}{\text{oven dry weight}} * 100\%$$

$$\text{Moisture content} = \left( \frac{2000 - 1960.207}{1960.207} \right) * 100 = 2.03\%$$

### C-3: Unit weight of coarse aggregate

Weight of measure + content = 27.865Kg

Weight of measure = 4.85 Kg

Net weight of aggregate = (weight of measure + content) – weight of measure

$$= 27.865 - 4.85 = 23.015Kg$$

$$\text{Volume of measure} = \frac{\pi d^2}{4} * h$$

$$d=0.255\text{m and } h=0.27\text{m}$$

$$\text{Volume of measure} = \pi * \frac{(0.255)^2}{4} * 0.27 = 0.01379\text{m}^3$$

$$\text{Unit weight of fine aggregate} = \frac{\text{net weight of aggregate}}{\text{volume of measure}} = \frac{23.015\text{Kg}}{0.0072\text{m}^3} = 1669 \text{ Kg/m}^3$$

#### C-4: Specific gravity for coarse aggregate

Weight of oven dry sample in air = 4888g = A

Weight of saturated – surface dry sample in air = 4959g = B

Weight of saturated sample in water = 3103.9g = C

$$\text{Bulk Specific gravity (relative density)} = \frac{A}{B-C} = \frac{4888}{4959-3103.9} = 2.635$$

$$\text{Bulk Specific gravity (relative density) SSD} = \frac{B}{B-C} = \frac{4959}{4959-3103.9} = 2.673$$

$$\text{Apparent Specific gravity} = \frac{A}{A-C} = \frac{4888}{4888-3103.9} = 2.739$$

$$\text{Absorption capacity (\%)} = \frac{B-A}{A} * 100 = \left( \frac{4959-4888}{4888} \right) * 100 = 1.4525\%$$

#### Appendix D- Tests for Marble waste powder

| Item No. | Description   | Test result               |      |
|----------|---|---------------------------|------|
| 1        | Fineness of marble waste powder (cm <sup>2</sup> /gm) | 2516.4                    |      |
| 2        | Specific gravity(gm/cm <sup>3</sup> )                 | 2.57                      |      |
| 3        | Cement consistency test                               | Water to cement ratio (%) | 24.5 |
|          |   | Water (gm)                | 73.5 |
|          |   | Penetration (mm)          | 11   |

#### D-1 Fineness of marble waste powder

Fineness is measured as a specific surface.

$$S = (S_s * \sqrt{T}) / \sqrt{T_s}$$

Where, S-Specific surface area of sample (m<sup>2</sup>/Kg)

S<sub>s</sub>-Specific surface area of sample used in calibration of the apparatus (m<sup>2</sup>/Kg)

T<sub>s</sub>- Measured time interval in second of manometer drop for standard sample used in the calibration apparatus.

T- Measured time interval in second of manometer drop for test sample

The following time intervals are obtained by using Baline's air permeability apparatus.

$$T_1 = 26.43 \text{ sec}$$

$$T_2 = 27.25 \text{ sec}$$

$$T_3 = 26.84 \text{ sec}$$

$$T_{avg} = \frac{T_1 + T_2 + T_3}{3} = \frac{26.43 + 27.25 + 26.84}{3} = 26.84 \text{ sec}$$

$$S = \frac{S_s * \sqrt{T}}{\sqrt{T_s}} = \frac{3400 * \sqrt{26.84}}{\sqrt{49}} = 2516.35 \text{ cm}^2/\text{g}$$

#### D-2 Specific gravity of marble waste powder

$$\rho = \frac{\text{mass of cement or marble (g)}}{\text{displaced volume (cm}^3\text{)}}$$

The displaced volume is obtained by a test done in the laboratory using Le Chatelier's Flask and kerosene or naphtha. The following results were obtained.

| Trial No. | Displaced volume (cm <sup>3</sup> ) |
|-----------|-------------------------------------|
| 1         | 19.3                                |
| 2         | 19.6                                |
| 3         | 19.46                               |

Mass of sample (marble waste powder) = 50g

$$\rho_1 = \frac{50\text{g}}{19.3 \text{ cm}^3} = 2.59 \text{ g/cm}^3$$

$$\rho_2 = \frac{50g}{19.6 \text{ cm}^3} = 2.551 \text{ g/cm}^3$$

$$\rho_3 = \frac{50g}{19.46 \text{ cm}^3} = 2.569 \text{ g/cm}^3$$

$$\rho_{avg} = \frac{(\rho_1 + \rho_2 + \rho_3)}{3} = (2.59 + 2.551 + 2.569)/3 = 2.57 \text{ g/cm}^3$$

### Appendix E-Tests for Ceramic Waste Powder

| Item No. | Description  | Test result               |     |
|----------|--|---------------------------|-----|
| 1        | Fineness of ceramic waste powder (cm <sup>2</sup> /gm) | 2046.93                   |     |
| 2        | Specific gravity(gm/cm <sup>3</sup> )                  | 2.5                       |     |
| 3        | Cement consistency test                                | Water to cement ratio (%) | 30  |
|          |  | Water (gm)                | 90  |
|          |  | Penetration (mm)          | 9.5 |

#### E-1 Fineness of ceramic waste powder

The following time intervals are obtained by using Baline's air permeability apparatus.

$$T_1 = 17.62 \text{ sec}$$

$$T_2 = 17.66 \text{ sec}$$

$$T_3 = 18 \text{ sec}$$

$$T_{avg} = \frac{T_1 + T_2 + T_3}{3} = \frac{17.62 + 17.66 + 18}{3} = 17.76 \text{ sec}$$

$$S = \frac{S_s * \sqrt{T}}{\sqrt{T_s}} = \frac{3400 * \sqrt{17.76}}{\sqrt{49}} = 2046.93 \text{ cm}^2/g$$

#### E-2 Specific gravity of ceramic waste powder

The displaced volume is obtained by a test done in the laboratory using Le Chatelier's Flask and kerosene or naphtha. The following results were obtained.

| Trial No. | Displaced volume (cm <sup>3</sup> ) |
|-----------|-------------------------------------|
| 1         | 20                                  |
| 2         | 20                                  |
| 3         | 20.1                                |

Mass of sample (marble waste powder) = 50g


$$\rho_1 = \frac{50g}{20cm^3} = 2.5 g/cm^3$$

$$\rho_2 = \frac{50g}{20 cm^3} = 2.5 g/cm^3$$

$$\rho_3 = \frac{50g}{20.1 cm^3} = 2.49 g/cm^3$$

$$\rho_{avg} = \frac{(\rho_1 + \rho_2 + \rho_3)}{3} = (2.5 + 2.5 + 2.49)/3 = 2.5 g/cm^3$$

### Complete silicate analysis report of marble and ceramic waste powder

|   |   |                            |               |
|---|---|----------------------------|---------------|
|  | <b>GEOLOGICAL SURVEY OF ETHIOPIA</b>      | Doc.Number:<br>GLD/F5.10.2 | Version No: 1 |
|   | <b>GEOCHEMICAL LABORATORY DIRECTORATE</b> |                            | Page 1 of 1   |
| Document Title:   | <b>Complete Silicate Analysis Report</b>  | Effective date:            | May, 2017     |

|   |                                       |
|---|---------------------------------------|
| Customer Name:- <u>Rihanna Nuru Abiyou</u>  | Issue Date: <u>-16/06/2021</u>        |
| Sample type :- <u>Soil</u>  | Request No:- <u>GLD/RO/947/21</u>     |
| Date Submitted :- <u>23/04/2021</u>   | Report No:- <u>GLD/RN/544/21</u>      |
| Analytical Result: <u>In percent (%) Element to be determined Major Oxides &amp; Minor Oxides</u> | Sample Preparation: - <u>200 Mesh</u> |
| Analytical Method: <u>LiBO<sub>2</sub> FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS</u>  | Number of Sample:- <u>Two (02)</u>    |

| Collector's code | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | CaO   | MgO  | Na <sub>2</sub> O | K <sub>2</sub> O | MnO   | P <sub>2</sub> O <sub>5</sub> | TiO <sub>2</sub> | H <sub>2</sub> O | LOI   |
|------------------|------------------|--------------------------------|--------------------------------|-------|------|-------------------|------------------|-------|-------------------------------|------------------|------------------|-------|
| Ceramic          | 70.50            | 16.72                          | 1.22                           | 1.14  | 3.72 | 1.42              | 3.46             | <0.01 | 0.17                          | 0.16             | 0.49             | 1.45  |
| Marble           | 2.24             | 1.21                           | <0.01                          | 51.44 | 0.94 | <0.01             | 1.32             | <0.01 | 0.15                          | 0.10             | 0.33             | 41.33 |

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

**Analysts**

Lidet Endeshaw  
Yirgalem Abreham  
Nigist Fikadu

**Checked By**

  
Tizita Zemene

**Approved By**

  
Yohannes Getachew

**Quality Control**

  
Gosa Haile



## Appendix F- Concrete mix design

### F-1: Mix Design for C-25 concrete

#### Step 1: - Material Data

| No | Test Description      | Cement | Fine Aggregate            | Coarse Aggregate        |
|----|-----------------------|--------|---------------------------|-------------------------|
| 1. | Specific Gravity      | 3.15   | 2.453 g/cm <sup>3</sup>   | 2.635 g/cm <sup>3</sup> |
| 2. | Unit Weight           | -      | 1490.97 Kg/m <sup>3</sup> | 1669 Kg/m <sup>3</sup>  |
| 3. | Moisture content      | -      | 1.523%                    | 2.03%                   |
| 4. | Water absorption      | -      | 2.27%                     | 1.4525%                 |
| 5. | Fineness modulus (FM) | -      | 2.6                       | 6.94                    |

#### Step 2: - Choice of Slump

According to ACI 211 Table: 6.3.1 (Recommended slumps for various types of construction), the recommended slump to address more frequent constructions of concrete we considered Beams, Columns, and reinforced walls whose slump ranges between 25mm to 100mm where maximum slump= 100mm, and minimum slump= 25mm

#### Step 3: - Choice of maximum aggregate size

Coarse aggregates =25mm

#### Step 4: - Estimation of Mixing water and Air content

From Table 6.3.3 of ACI standards (Approximate mixing water and air content requirements for different slumps and nominal maximum aggregate of aggregates), considering non-air-entrained concrete and for non-air-entrained and slump of 75 mm-100 mm, the water in 1m<sup>3</sup> of concrete is 193kg.

#### Step 5: - Selection of Water to Cement ratio (W/C)

According to Table 6.3.4 (a) (Relationship between water – cement or water – cementitious materials ratio and compressive strength of concrete), for the slump of 75mm to 100mm, water to cement ratio is 0.61

#### Step 6: - Calculation of Cement content

Cement content (kg) per cubic meter of concrete is = $water / (\frac{W}{C}) = 193 / 0.61 = 316.39 \text{kg/m}^3$

**Step 7: - Estimation of Coarse Aggregate (CA) content**

According to Table 6.3.6 (Volume of coarse aggregate per unit volume of concrete), for Fineness modulus of fine aggregate (F.M) = 2.6 and Maximum aggregate size = 25mm, the volume of oven dry – rodded coarse aggregate per cubic meter of concrete is 0.69. The mass of coarse aggregate can be estimated as:

$$C.A = 0.69 * 1669 = 1151.61 \text{ kg/m}^3$$

**Step 8: - Estimation of fine Aggregates (FA) content**

*Content of fine aggregate(F.A) = unit weight of concrete – (C.A + cement + water)*

From Table 6.3.7.1 (First estimate of weight of fresh concrete), the unit weight of fresh concrete corresponding to the maximum aggregate size of 25mm and non-air entrained is 2380kg/m<sup>3</sup>.

$$F.A = [2380 - (1151.61 + 316.39 + 193)] = 718.99 \text{ kg/m}^3$$

**Step 9: - Adjustment for aggregate moisture**

If absorption capacity is greater than the moisture content of aggregate, we need to add water up to its moisture capacity.

$$C.A_{\text{water}} = 1.4525\% - 2.03\% = - 0.5775\%$$

$$F.A_{\text{water}} = 2.27\% - 1.523\% = 0.747\%$$

$$\text{Total water required} = 193 + [718.99 * 0.747\% - 1151.62 * 0.5775\%] = 191.72 \text{ kg/m}^3$$

The estimated ingredients for a meter cube of concrete are, therefore, summarized as follows.

| No | Ingredients      | Weight (kg/m <sup>3</sup> ) |
|----|------------------|-----------------------------|
| 1. | Cement           | 316.4                       |
| 2. | Fine Aggregate   | 718.99                      |
| 3. | Coarse Aggregate | 1151.61                     |
| 4. | Water            | 191.72                      |

### Trial batches

The trial batch is concerned on the findings of compressive, splitting tensile and flexural strength tests for 7 and 28 days.

|                | Mix Number |      |    |     |      |      |    |    |    |    |      |    |      |
|----------------|------------|------|----|-----|------|------|----|----|----|----|------|----|------|
|                | 1          | 2    | 3  | 4   | 5    | 6    | 7  | 8  | 9  | 10 | 11   | 12 | 13   |
| <b>Cement</b>  | 100        | 92.5 | 90 | 90  | 87.5 | 87.5 | 85 | 95 | 90 | 85 | 97.5 | 95 | 92.5 |
| <b>Marble</b>  | 0          | 5    | 5  | 7.5 | 7.5  | 10   | 10 | 5  | 10 | 15 | 0    | 0  | 0    |
| <b>Ceramic</b> | 0          | 2.5  | 5  | 2.5 | 5    | 2.5  | 5  | 0  | 0  | 0  | 2.5  | 5  | 7.5  |

### Quantities in kg/ m<sup>3</sup>

|                | Mix Number |       |       |       |       |       |       |       |       |       |       |       |       |
|----------------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                | 1          | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13    |
| <b>Cement</b>  | 316.4      | 292.7 | 284.7 | 284.8 | 276.8 | 276.8 | 268.9 | 300.6 | 284.7 | 268.9 | 308.5 | 300.6 | 292.6 |
| <b>Marble</b>  | 0          | 15.82 | 15.82 | 23.7  | 23.7  | 31.6  | 31.6  | 15.8  | 31.6  | 47.5  | 0     | 0     | 0     |
| <b>Ceramic</b> | 0          | 7.91  | 15.82 | 7.91  | 15.8  | 7.91  | 15.8  | 0     | 0     | 0     | 7.91  | 15.8  | 23.7  |

### Sample calculations for Compressive and Splitting tensile strength tests

$$\text{Volume of cube} = 0.15^3 * 6 = 0.02025m^3$$

$$\text{Volume of cylinder} = \pi * 0.15^2 * 0.3 * \frac{6}{4} = 0.0318m^3$$

$$\text{Total volume} = 0.02025m^3 + 0.0318m^3 = 0.0521m^3$$

Considering 15% of wastage

$$\frac{15}{100} * 0.0521 + 0.0521 = 0.0599m^3$$

Therefore, the following results are obtained

$$\text{Coarse aggregate} = 0.0599m^3 * \frac{1151.61kg}{m^3} = 68.98kg$$

$$\text{Fine aggregate} = 0.0599m^3 * \frac{718.99kg}{m^3} = 43.067kg$$

$$\text{Cement} = 0.0599m^3 * \frac{316.4kg}{m^3} = 18.95kg$$

Partial Replacement of Cement with Marble and Ceramic Waste Powders in Normal  
Strength Concrete

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$$\text{Water} = 0.0599\text{m}^3 * \frac{191.72\text{kg}}{\text{m}^3} = 11.484\text{kg}$$

The altering parameter is the value of cement where the rest ingredients are kept constant. Fine aggregate = 43.067kg, Coarse aggregate = 68.98kg, and water = 11.484kg. The following table summarizes the value of cement, marble and ceramic waste powder used for the different mixes.

| Mix No. | Cement(kg) | Marble(kg) | Ceramic(kg) |
|---------|------------|------------|-------------|
| 1       | 18.95      | 0          | 0           |
| 2       | 17.53      | 0.946      | 0.473       |
| 3       | 17.055     | 0.947      | 0.947       |
| 4       | 17.055     | 1.42       | 0.47375     |
| 5       | 16.58      | 1.422      | 0.948       |
| 6       | 16.58      | 1.896      | 0.474       |
| 7       | 16.1075    | 1.895      | 0.9475      |

For the following mixes, the tests have been carried out for only 28<sup>th</sup> day, therefore, Fine aggregate = 21.57kg, Coarse aggregate= 34.5kg and water= 5.75kg. The values of cement replacement by the marble and ceramic waste powders are summarized in the following table.

| Mix No. | Cement(kg) | Marble(kg) | Ceramic(kg) |
|---------|------------|------------|-------------|
| 8       | 9.0174     | 0.4746     | 0           |
| 9       | 8.542      | 0.949      | 0           |
| 10      | 8.0682     | 1.4238     | 0           |
| 11      | 9.2547     | 0          | 0.2373      |
| 12      | 9.0174     | 0          | 0.474       |
| 13      | 8.7801     | 0          | 0.7119      |

**MIX 1 (C-25, 0%)**

Cement -100%, Marble -0, Ceramic -0

Coarse aggregate = 68.98kg

Fine aggregate = 43.067kg

Cement = 18.95kg

Water = 11.484 kg

**MIX 7 (C-25, 15%)**

Cement -85%, Marble -10%, Ceramic - 5%

Coarse aggregate = 68.98kg

Fine aggregate = 43.067kg

Water = 11.484 kg

Cement =  $268.94 \text{ Kg/m}^3 * 0.0599 \text{ m}^3 = 16.1075 \text{ kg}$

Marble,  $31.64 \frac{\text{Kg}}{\text{m}^3} * 0.0599 \text{ m}^3 = 1.895 \text{ kg}$

Ceramic,  $15.82 \frac{\text{Kg}}{\text{m}^3} * 0.0599 \text{ m}^3 = 0.9475 \text{ kg}$

**Sample calculation for Flexural strength test**

Volume of member beam =  $0.1 * 0.1 * 0.5 = 0.005 \text{ m}^3$

$$3 * 0.005 \text{ m}^3 = 0.015 \text{ m}^3$$

Considering 15% of wastage

$$\frac{15}{100} * 0.015 + 0.015 = 0.01725 \text{ m}^3$$

Therefore, the following results are obtained

Coarse aggregate =  $0.01725 \text{ m}^3 * \frac{1151.61 \text{ kg}}{\text{m}^3} = 19.865 \text{ kg}$

Fine aggregate =  $0.01725 \text{ m}^3 * \frac{718.99 \text{ kg}}{\text{m}^3} = 12.4 \text{ kg}$

Cement =  $0.01725 \text{ m}^3 * 316.4 \frac{\text{Kg}}{\text{m}^3} = 5.46 \text{ kg}$

Water =  $0.01725 \text{ m}^3 * 191.72 \frac{\text{Kg}}{\text{m}^3} = 3.31 \text{ kg}$

**MIX 1 (C-25, 0%)**

Cement -100%, Marble -0, Ceramic -0

Coarse aggregate = 19.86kg

Fine aggregate = 12.4kg

Cement = 5.46kg

Water = 3.31 kg

**MIX 7 (C-25, 15%)**

Cement -85%, Marble -10%, Ceramic - 5%

$$\text{Cement} = 268.94 \frac{\text{Kg}}{\text{m}^3} * 0.01725 \text{ m}^3 = 4.64 \text{ kg}$$

$$\text{Marble, } 31.64 \frac{\text{Kg}}{\text{m}^3} * 0.01725 \text{ m}^3 = 0.546 \text{ kg}$$

$$\text{Ceramic, } 15.82 \frac{\text{Kg}}{\text{m}^3} * 0.01725 \text{ m}^3 = 0.273 \text{ kg}$$

**Appendix G-Test Results for Compressive, Splitting Tensile and Flexural Strength of Concrete**

**G-1: Test Results for Compressive Strength**

| Mix notation | Test age | Weight (g) | Failure load (KN) | Compressive strength (MPa) | Average Compressive strength (MPa) |
|--------------|----------|------------|-------------------|----------------------------|------------------------------------|
| <b>M-1</b>   | 7        | 8389       | 501.5             | 22.29                      | 22.306                             |
|              |          | 8553       | 503.5             | 22.38                      |                                    |
|              |          | 8319       | 426               | 22.25                      |                                    |
|              | 28       | 8475       | 680.6             | 30.25                      | 30.16                              |
|              |          | 8309       | 697.5             | 31                         |                                    |
|              |          | 8409       | 657.6             | 29.23                      |                                    |
| <b>M-2</b>   | 7        | 8453       | 477.6             | 21.23                      | 21.26                              |

Partial Replacement of Cement with Marble and Ceramic Waste Powders in Normal  
Strength Concrete

| Mix notation | Test age | Weight (g) | Failure load (KN) | Compressive strength (MPa) | Average Compressive strength (MPa) |
|--------------|----------|------------|-------------------|----------------------------|------------------------------------|
|              |          | 8556       | 495.8             | 22.03                      | 32.48                              |
|              |          | 8566       | 460.2             | 20.45                      |                                    |
|              | 28       | 8349       | 734.5             | 32.64                      |                                    |
|              |          | 8482       | 724.5             | 32.2                       |                                    |
|              |          | 8390       | 733.6             | 32.6                       |                                    |
| <b>M-3</b>   | 7        | 8337       | 360               | 16                         | 16.126                             |
|              |          | 8204       | 358               | 15.91                      |                                    |
|              |          | 8379       | 370.6             | 16.47                      |                                    |
|              | 28       | 8243       | 675               | 30                         | 30                                 |
|              |          | 8379       | 672.8             | 29.9                       |                                    |
|              |          | 8406       | 677.25            | 30.1                       |                                    |
| <b>M-4</b>   | 7        | 8280       | 340.5             | 15.13                      | 15.1                               |
|              |          | 8354       | 349.5             | 15.53                      |                                    |
|              |          | 8231       | 329.4             | 14.64                      |                                    |
|              | 28       | 8197       | 621.9             | 27.64                      | 27.36                              |
|              |          | 8160       | 610.5             | 27.13                      |                                    |
|              |          | 8265       | 614.7             | 27.32                      |                                    |
| <b>M-5</b>   | 7        | 8521       | 419.7             | 18.65                      | 17.56                              |
|              |          | 8459       | 365.1             | 16.23                      |                                    |
|              |          | 8484       | 401               | 17.82                      |                                    |
|              | 28       | 8406       | 667.9             | 29.68                      | 30.02                              |
|              |          | 8422       | 676               | 30.04                      |                                    |
|              |          | 8480       | 682.4             | 30.33                      |                                    |
| <b>M-6</b>   | 7        | 8322       | 425.7             | 18.92                      | 18.3                               |
|              |          | 8407       | 421.1             | 18.98                      |                                    |
|              |          | 8294       | 382.2             | 17                         |                                    |

Partial Replacement of Cement with Marble and Ceramic Waste Powders in Normal  
Strength Concrete

| Mix notation | Test age | Weight (g) | Failure load (KN) | Compressive strength (MPa) | Average Compressive strength (MPa) |
|--------------|----------|------------|-------------------|----------------------------|------------------------------------|
|              | 28       | 8403       | 640.8             | 28.48                      | 29.61                              |
|              |          | 8323       | 661.4             | 29.39                      |                                    |
|              |          | 8313       | 696.9             | 30.97                      |                                    |
| M-7          | 7        | 8340       | 428.5             | 19.04                      | 18.9                               |
|              |          | 8394       | 405.2             | 18.01                      |                                    |
|              |          | 8366       | 442.6             | 19.67                      |                                    |
|              | 28       | 8452       | 683.1             | 30.36                      | 31                                 |
|              |          | 8301       | 688.4             | 30.6                       |                                    |
|              |          | 8478       | 721               | 32.05                      |                                    |
| M-8          | 28       | 8159       | 656.8             | 29.19                      | 30.39                              |
|              |          | 8225       | 681.6             | 30.29                      |                                    |
|              |          | 8162       | 648.5             | 28.82                      |                                    |
| M-9          | 28       | 8132       | 634.1             | 28.18                      | 29.43                              |
|              |          | 8304       | 709.9             | 31.55                      |                                    |
|              |          | 8249       | 707.8             | 31.46                      |                                    |
| M-10         | 28       | 8352       | 610               | 27.11                      | 26.53                              |
|              |          | 8469       | 563.6             | 25.05                      |                                    |
|              |          | 8429       | 616.9             | 27.42                      |                                    |
| M-11         | 28       | 8427       | 723               | 32.13                      | 31.65                              |
|              |          | 8165       | 658.9             | 29.29                      |                                    |
|              |          | 8472       | 754.9             | 33.55                      |                                    |
| M-12         | 28       | 8587       | 698.1             | 31.02                      | 30.35                              |
|              |          | 8231       | 619.6             | 27.54                      |                                    |
|              |          | 8429       | 731.6             | 32.51                      |                                    |
| M-13         | 28       | 8418       | 560.3             | 24.9                       | 27.25                              |
|              |          | 8219       | 617.8             | 27.46                      |                                    |
|              |          | 8425       | 661.5             | 29.4                       |                                    |

**G-2: Test Results for Splitting Tensile Strength**

| Mix notation | Test age | Weight (g) | Failure load (KN) | Splitting tensile strength (MPa) | Average Splitting tensile strength (MPa) |
|--------------|----------|------------|-------------------|----------------------------------|--|
| M-1          | 7        | 12940      | 178.84            | 2.53                             | 2.43                                     |
|              |          | 13195      | 159.04            | 2.25                             |  |
|              |          | 12925      | 178.13            | 2.52                             |  |
|              | 28       | 13226      | 221.25            | 3.13                             | 3.34                                     |
|              |          | 13107      | 234.67            | 3.32                             |  |
|              |          | 13149      | 251.64            | 3.56                             |  |
| M-2          | 7        | 13067      | 176.71            | 2.5                              | 2.57                                     |
|              |          | 13042      | 191.55            | 2.71                             |  |
|              |          | 13172      | 176.71            | 2.5                              |  |
|              | 28       | 13052      | 258.71            | 3.66                             | 4.14                                     |
|              |          | 13101      | 286.27            | 4.05                             |  |
|              |          | 13185      | 332.93            | 4.71                             |  |
| M-3          | 7        | 13014      | 148.44            | 2.1                              | 2.25                                     |
|              |          | 13125      | 164.69            | 2.33                             |  |
|              |          | 12950      | 163.99            | 2.32                             |  |
|              | 28       | 13025      | 265.07            | 3.75                             | 3.53                                     |
|              |          | 12984      | 242.45            | 3.43                             |  |
|              |          | 12989      | 241.04            | 3.41                             |  |
| M-4          | 7        | 13114      | 166.11            | 2.35                             | 2.373                                    |
|              |          | 13043      | 167.53            | 2.37                             |  |
|              |          | 13102      | 169.65            | 2.4                              |  |
|              | 28       | 13251      | 146.32            | 2.07                             | 2.77                                     |
|              |          | 13131      | 270.73            | 3.83                             |  |
|              |          | 13106      | 171.76            | 2.43                             |  |
| M-5          | 7        | 13270      | 166.11            | 2.35                             | 2.43                                     |
|              |          | 13209      | 175.30            | 2.48                             |  |
|              |          | 13074      | 173.18            | 2.45                             |  |
|              | 28       | 13102      | 207.11            | 2.93                             | 3.19                                     |
|              |          | 13146      | 252.35            | 3.57                             |  |
|              |          | 13312      | 217.01            | 3.07                             |  |
| M-6          | 7        | 13327      | 155.51            | 2.2                              | 2.11                                     |
|              |          | 13160      | 148.44            | 2.1                              |  |

Partial Replacement of Cement with Marble and Ceramic Waste Powders in Normal Strength Concrete

| Mix notation | Test age | Weight (g) | Failure load (KN) | Splitting tensile strength (MPa) | Average Splitting tensile strength (MPa) |
|--------------|----------|------------|-------------------|----------------------------------|--|
|              | 28       | 13085      | 142.78            | 2.02                             | 2.44                                     |
|              |          | 13215      | 197.21            | 2.79                             |  |
|              |          | 13111      | 144.2             | 2.04                             |  |
|              |          | 13280      | 176.71            | 2.5                              |  |
| M-7          | 7        | 13052      | 185.19            | 2.62                             | 2.37                                     |
|              |          | 13320      | 143.49            | 2.03                             |  |
|              |          | 13087      | 175.3             | 2.48                             |  |
|              | 28       | 13441      | 180.25            | 2.55                             | 2.64                                     |
|              |          | 13002      | 202.87            | 2.87                             |  |
|              |          | 13100      | 177.42            | 2.51                             |  |
| M-8          | 28       | 13086      | 197.21            | 2.79                             | 2.813                                    |
|              |          | 13057      | 197.92            | 2.8                              |  |
|              |          | 13183      | 201.45            | 2.85                             |  |
| M-9          | 28       | 13094      | 190.14            | 2.69                             | 2.79                                     |
|              |          | 13303      | 194.38            | 2.75                             |  |
|              |          | 12973      | 206.4             | 2.92                             |  |
| M-10         | 28       | 13046      | 207.82            | 2.94                             | 2.52                                     |
|              |          | 13304      | 162.57            | 2.3                              |  |
|              |          | 13174      | 165.41            | 2.34                             |  |
| M-11         | 28       | 13184      | 228.32            | 3.23                             | 3.22                                     |
|              |          | 13128      | 229.02            | 3.24                             |  |
|              |          | 13163      | 225.48            | 3.19                             |  |
| M-12         | 28       | 13065      | 216.29            | 3.06                             | 3.186                                    |
|              |          | 12926      | 233.26            | 3.3                              |  |
|              |          | 13059      | 226.19            | 3.2                              |  |
| M-13         | 28       | 12997      | 190.85            | 2.7                              | 2.86                                     |
|              |          | 13099      | 211.35            | 2.99                             |  |
|              |          | 13053      | 204.28            | 2.89                             |  |

**G-3: Test Results for Flexural Strength**

| Mix notation | Test age | Weight | Failure load (KN) | Flexural strength (MPa) | Average flexural strength (MPa) |
|--------------|----------|--------|-------------------|-------------------------|---------------------------------|
| <b>M-1</b>   | 28       | 12064  | 10.7              | 3.2                     | 3.196                           |
|              |          | 12043  | 10.7              | 3.21                    |                                 |
|              |          | 12044  | 10.6              | 3.18                    |                                 |
| <b>M-2</b>   | 28       | 12112  | 9.7               | 2.89                    | 2.7                             |
|              |          | 11925  | 8.5               | 2.54                    |                                 |
|              |          | 12110  | 8.9               | 2.67                    |                                 |
| <b>M-3</b>   | 28       | 12121  | 11.5              | 3.46                    | 3.31                            |
|              |          | 12014  | 10.4              | 3.11                    |                                 |
|              |          | 12010  | 11.2              | 3.36                    |                                 |
| <b>M-4</b>   | 28       | 12763  | 12.1              | 3.62                    | 3.83                            |
|              |          | 12834  | 13.3              | 3.99                    |                                 |
|              |          | 12830  | 12.96             | 3.89                    |                                 |
| <b>M-5</b>   | 28       | 12096  | 7.9               | 2.36                    | 2.62                            |
|              |          | 12134  | 9.3               | 2.8                     |                                 |
|              |          | 12132  | 9                 | 2.7                     |                                 |
| <b>M-6</b>   | 28       | 12570  | 8.7               | 2.6                     | 2.48                            |
|              |          | 12126  | 7.9               | 2.36                    |                                 |
|              |          | 12450  | 8.33              | 2.5                     |                                 |
| <b>M-7</b>   | 28       | 12664  | 6.4               | 1.96                    | 2.14                            |
|              |          | 12707  | 7.7               | 2.3                     |                                 |
|              |          | 12705  | 7.33              | 2.2                     |                                 |

**Appendix H- Sample calculation and results for Chemical shrinkage of concrete**

$$M_{\text{cement}} = \frac{M(\text{vial} + \text{paste}) - M_{\text{vial}}}{\left(1 + \frac{w}{c}\right)}$$

Where:  $M_{\text{cement}}$  = mass of cement

$M_{\text{(vial + paste)}}$  = mass of vial glass plus paste

w/c = water to cement ratio (0.4)

$$CS(t) = \frac{[h(t) - h(60 \text{ min})]}{M_{\text{cement}}}$$

Where: CS (t) = chemical shrinkage at time t

h (t) = height in the capillary tube at time t

$M_{\text{vial}} = 144.4 \text{ g}$

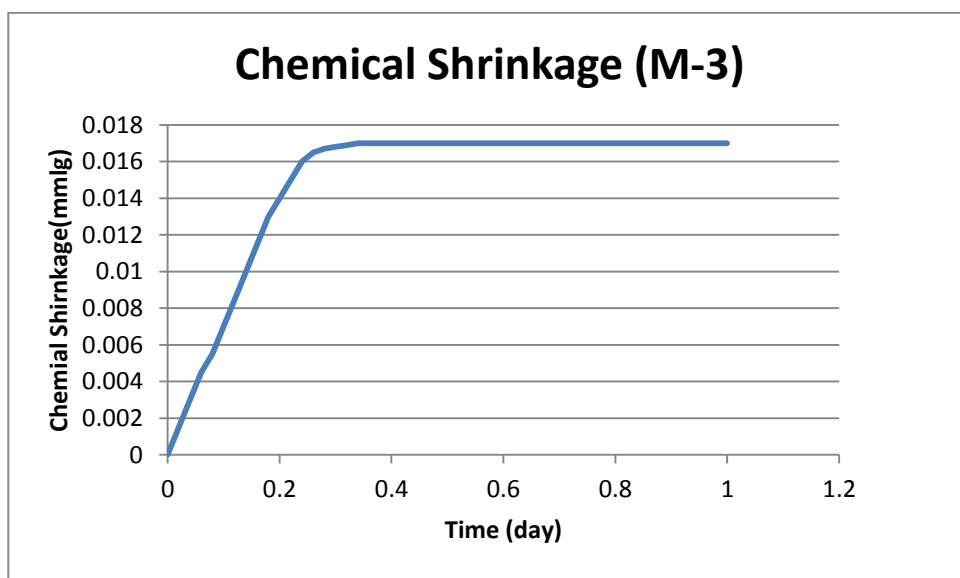
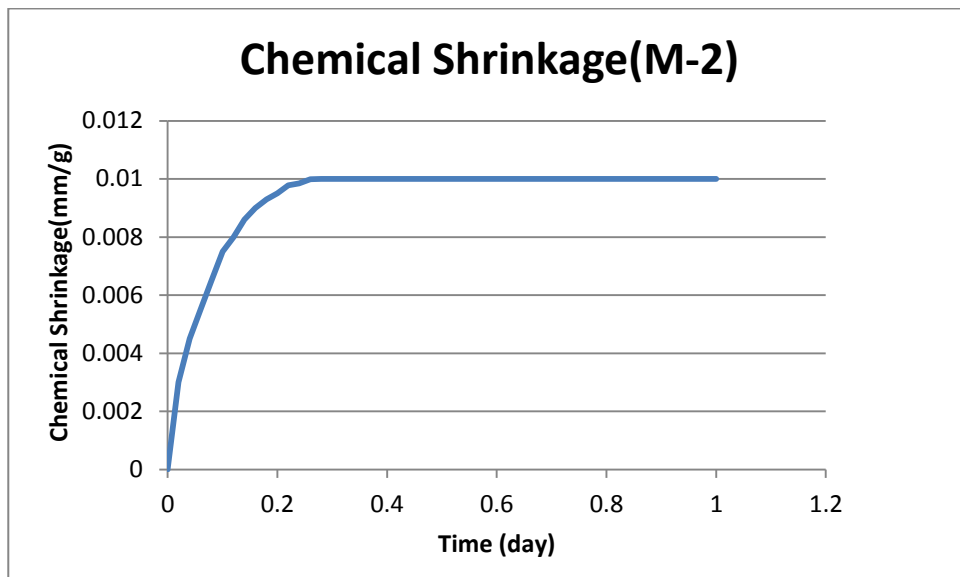
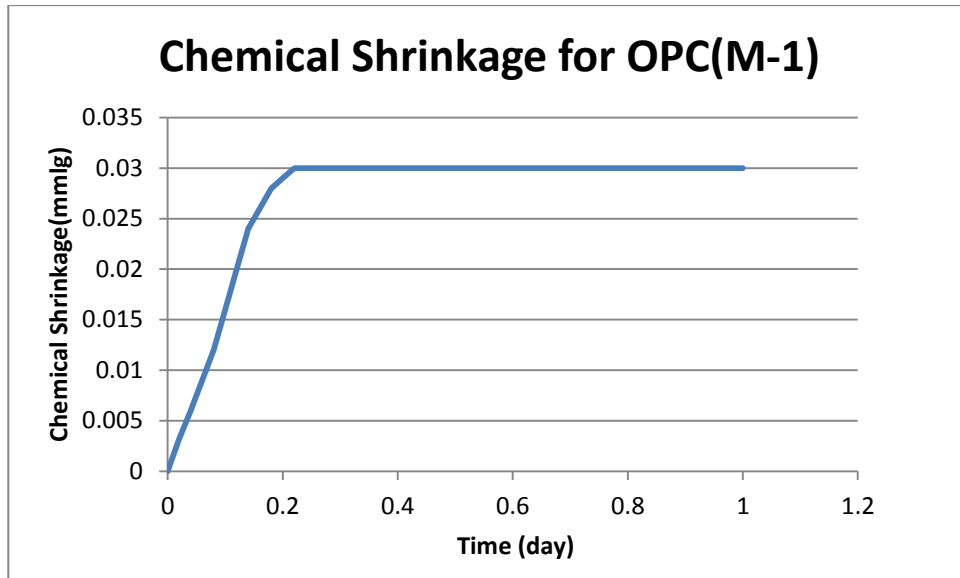
$M_{\text{(vial + paste)}} = 251 \text{ g}$

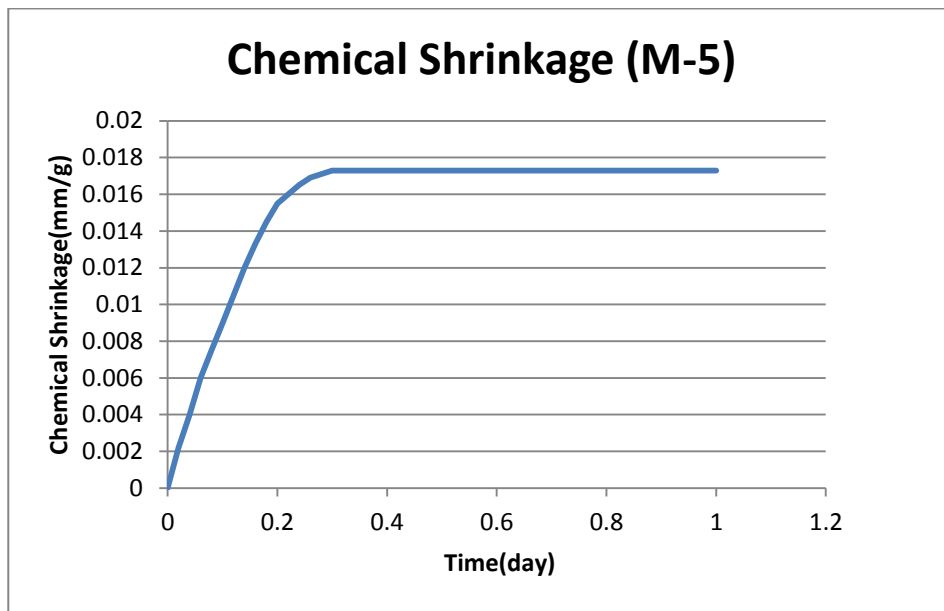
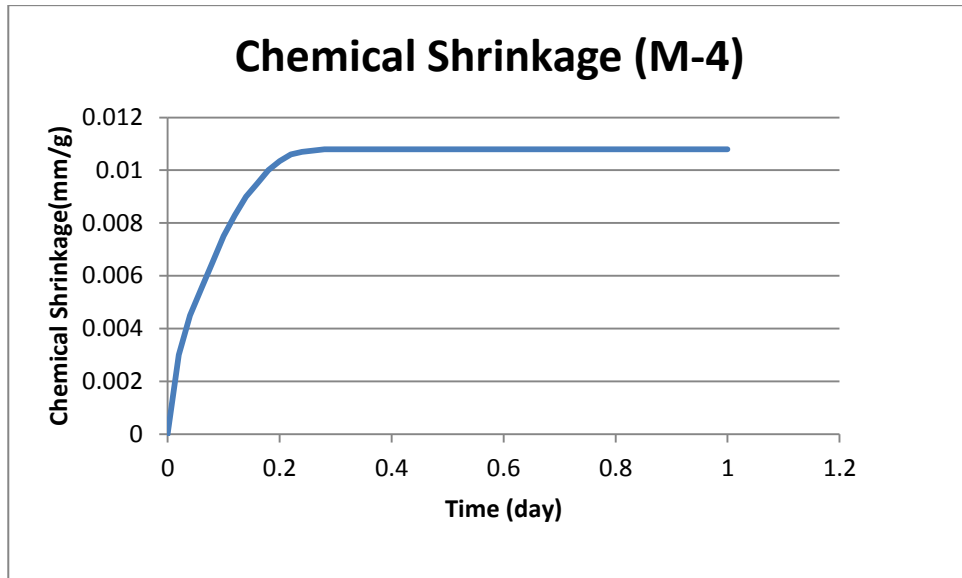
$$M_{\text{cement}} = \frac{251 \text{ g} - 144.4 \text{ g}}{(1 + 0.4)} = 76.14 \text{ g}$$

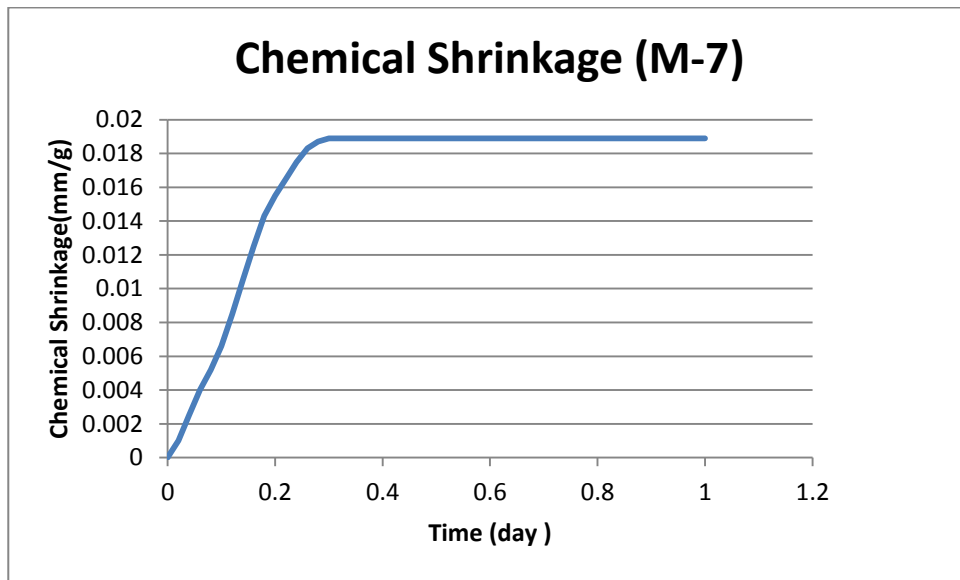
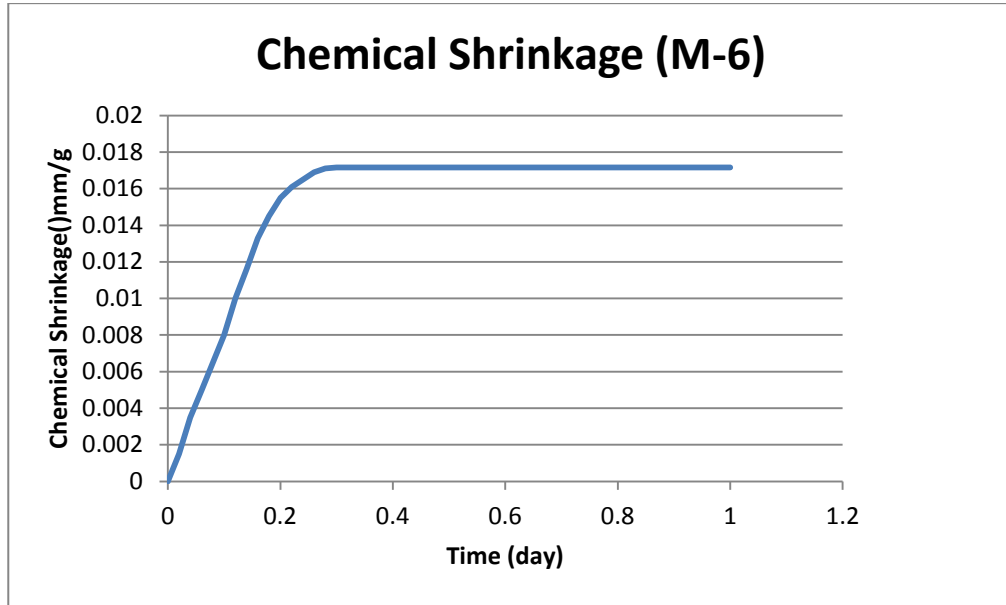
h (60min) = 0.1 ml

h (24h) = 2.39 ml

$$CS(t) = \frac{[2.39 \text{ ml} - 0.1 \text{ ml}]}{76.14 \text{ g}} = 0.03 \text{ ml/g}$$







**Appendix I- Pictures**



Ceramic wastes



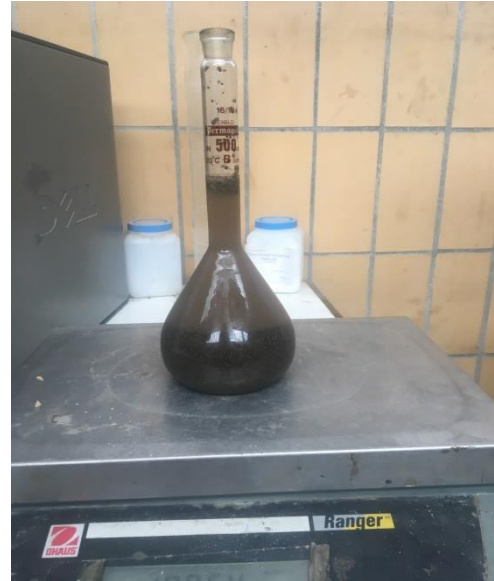
Marble wastes



Marble and ceramic waste powders ready for mix

## Partial Replacement of Cement with Marble and Ceramic Waste Powders in Normal Strength Concrete

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Performing physical properties



Beam member casted and ready for flexural strength test