Jimma University
School of Graduate Studies
Jimma Institute of Technology
School of Civil and Environmental Engineering
Construction Engineering and Management Stream

Study on Marble Dust Powder as Partial Replacement of Cement in Concrete

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering (Construction Engineering & Management)

By
Tatek Mengistu Dadi

October, 2016
Jimma, Ethiopia

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Advisor: Dr.-Ing Esayas Alemayehu

Co-advisor: Engr. Getachew Kebede

October, 2016

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Declaration

I, the undersigned declare that this thesis entitled "**study on marble dust powder as partial replacement of cement in concrete.**" is my original work, and has not been presented by any other person for an award of degree in this or any other University, and all sources of materials used for theses have been dually acknowledged.

Candidate:

Mr. Tatek Mengistu

Signature ____________________

As master research Advisors, we hereby certify that we have read and evaluate this MSc research prepared under our guidance, by Mr. Tatek Mengistu entitled: **study on marble dust powder as partial replacement of cement in concrete.**

We recommend that it can be submitted as full filling the MSc Thesis requirements.

Dr.-Ing Esayas Alemayehu	____________________	____________________
Advisor	Signature	Date
Engr. Getachew Kebede	____________________	____________________
Co-Advisor	Signature	Date

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ABSTRACT

Marble dust powder is a by-product of the marble processing industries which is generated during cutting, shaping and polishing process; already causing environmental problems around the marble processing industries. Due to the boosting of the construction activity in the country, a huge shortage is created in most of the construction materials especially cement, resulting in increase of price. Therefore, this research was conducted to examine the potential of marble dust powder as partial replacement of cement in concrete.

Initially, marble dust powder samples were collected from Ethio-marble Processing Enterprise. Then marble dust powder was sieved until the particles passing the 90µm reaches more than 90%, which is similar to that of Ordinary Portland Cement (OPC). OPC was replaced by marble dust powder. Normal consistency and setting time of the pastes containing OPC and marble dust powder from 4% to 20% replacement were investigated. The compressive strength, flexural strength, tensile split strength and permeability of concrete containing OPC with marble dust powder from 4% to 20% replacements was also investigated. Six different concrete mixes with the replacing 0%, 4%, 8%, 12%, 16% and 20% of the OPC were prepared for characteristic strength of 25MPa concrete with water to cement ratio of 0.50 and 340kg/m^3 cement content. Then the properties of these mixes have been assessed both at the fresh and hardened state.

The results of the concrete work have shown that, up to 8% replacement of the OPC by marble dust powder achieved a higher compressive strength, whereas the 12%, 16% and 20% replacement of the cement by marble dust powder in the concrete have shown a slightly lower compressive strength. The water penetration depth was found to decrease as the marble dust powder content increases and all the blended concretes showed a lower maximum penetration depth than the control concrete.

Therefore it can be concluded that 8% replacement of cement by marble dust powder shows satisfactory concrete properties and higher replacement could also be recommended with a slight reduction in the performance of the concrete.

***Keywords**: - Cement, Concrete, Marble Dust Powder, Performance of Concrete*

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CA	Coarse Aggregate
DOE	Department of Envaronment
EN	Europian Standard
ES	Ethiopian Standard
FA	Fine Aggregate
KN	Kilo Newton
MDP	Marble Dust Powder
Mpa	Megga Pascal (N/mm^2)
OPC	Ordinary Portland Cement
PCA	Portland cement Association
PCC	Portland cement Concrete
PSD	Particle Size Distirbution
SEM	Scanning Electron Microscopy
SSD	Saturated Surface Dry
W/C	Water To Cement Ratio
WMP	Waste Marble Powder
XRD	X-Ray Diffraction

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CHAPTER ONE

INTRODUCTION

1.1 Background

In developing countries, the methods used to recycle and re-use waste materials should be investigated in order to benefit from natural resources effectively. Conversion of raw materials, used or waste materials provides significant energy savings by reducing the number of industrial processes in the production of materials (Ismail and Ramli, 2013).

In our country, there are a lot of waste materials which have economic value. One of them is waste marble. Marble is a metamorphic rock, such as limestone, that contains largely calcium carbonate (Topcu et al., 2009; Topcu IB and Uygunoglu, 2009). Furthermore, in marble, small amounts of silica, feldspar, iron oxide, mica, fluorine and organic matters may be found. Today, as a result of an increased demand for marble in the country and in the world in general, the number of marble businesses has also increased. The number of processed blocks of marble has also increased in facilities, due to the increase in production (Topcu et al., 2009; Saboya et al., 2007).

The marble dust and crumbs of up to 60% of marble blocks are dumped into the streams near factories or in disposal sites (Cengiz and Kulaksiz, 1996). Particularly, in areas where there is a concentration of marble business facilities, the marble waste causes the proliferation of the disposal sites (Terzi and Karasahin, 2003; Hebhoub et al., 2011). In general, this type of waste is used as fill material in floor and wall tiles for decorative purposes. In the literature, many studies have been conducted on the use of waste marble dust. However, studies on the re-use of marble pieces are very limited (Terzi and Karasahin, 2003; Andre et al., 2013; Thomas and Gupta, 2013; Gazi et al., 2012). The destruction of the environment would be reduced by the use of waste pieces of marble as aggregate in concrete and its powders as cement. On the other hand, the use of marble waste will contribute directly to the evaluation of environmental waste.

The concrete industry will be called upon to serve the two pressing needs of human society; namely, protection of the environment and meeting the infrastructural requirement for increasing industrialization and urbanization of the world. Also due to large size, the concrete industry is unquestionably the ideal medium for the economic and safe use of millions of tons of industrial byproducts such as fly ash and slag due to their highly pozzolanic and cementitious properties. It is obvious that large-scale cement replacement 60 - 70% in concrete with these industrial by-products will be advantageous from the standpoint of cost economy, energy efficiency, durability, and overall ecological profile of concrete. Therefore, in the future, the use of by-product supplementary cementing materials ought to be made mandatory (Malhotra, 2004).

Concrete is the most commonly used construction material in the world. It is basically composed of two components: paste and aggregate. The paste contains cement, water and sometimes other cementitious and chemical admixtures, whereas the aggregate contains sand and crushed stone. The paste binds the aggregates together. The aggregates are relatively inert filler materials which occupy more percentage of the concrete and can therefore be expected to have influence on its properties (Mindess et al., 2003). The proportion of these components, the paste and the aggregate is controlled by; the strength and durability of the desired concrete, the workability of the fresh concrete and the cost of the concrete.

Conventionally, cement is a powdered material that has plays a great role in concrete as a binder, but is the most expensive and environmentally unfriendly material. Therefore, requirements for economical and more environmental friendly cementing materials have extended interest in other cementing materials that can be used as normal Portland cement.

Therefore, this study attempts to make use of the marble dust powder produced in marble processing industries found in Ethiopia as cement replacing material in concrete. An experimental study was carried out to examine the influence of adding marble dust powder to cement on the mechanical and physical properties of pastes and concretes such as consistency, setting time, workability, compressive strength, flexural strength, tensile split strength and water permeability.

1.2 Statement of the Problem

Nowadays, marbles are used for the decoration purpose, which increases its demand in the market. With the increase in production of marbles it increases the waste that obtained from it. As marble powder is the waste product, obtained during the process of sawing and shaping of marble by parent marble rock, contains heavy metals which makes the water unfit for use. Marble powder creates environmental problems. Due to environmental problems, it has a great impact on human health as well as on nature (Sharma and Kumar, 2015).

Currently, the number of companies processing marble products becomes increased in the Ethiopia; simultaneously the amount of waste generated from these factories also becomes increased. One of waste of this process is released in the form of dust particles in and around the marble processing industries. These fine particles (marble dust powder) are carried by the wind; suspend in the air and probably causes the respiratory problem.

On the other hand, the production of cement is one of the most environmental unfriendly processes due to the release of CO_2 gases to the atmosphere. Nowadays, a great problem for this world is global warming which is caused by depletion of natural resources and emission of gases during cement production. According to Naik T.R. and Moriconi G. (2006), one ton of Portland cement clinker production generates approximately about one ton of CO_2 and other greenhouse gases. This shows that the cement industry contributes to today's worldwide concern, which is global warming.

In addition to its negative environmental impact, the cost of cements and cement based construction materials in Ethiopia is increasing from time to time and resulted for huge gap between demand and supply of cement throughout the country. This rise of cost and demand of cement is mainly due to limited production capacity and restricted types of cement produced in the country for the steady increase in demand of cement for construction (Gudissa and Dinku, 2010).

Thus this thesis deals with the use of marble dust powder in construction industry to address environmental problem due to the waste and to seek alternative cement and cement based material and for efficient use of natural resources in Ethiopia.

1.3 Research Questions

In view of all of the above statement of the problems, the following research questions have been considered with the aim of examining the problems critically and look for potential solutions and suggest them on the way:

1. Can we utilize marble dust powder as a partial replacement of cement in concrete?
2. What percentage of cement shall be replaced by marble dust powder to produce effective concrete mix?
3. Is there a significance difference between performance of conventional concrete and marble dust powder blended concretes?
4. Does partial replacement of cement by marble dust powder enhances concrete strength?

1.4 Objectives of the Research

1.4.1 General Objective

The main objective of this research is to study on the application of marble dust powder as partial replacement of cement in concrete.

1.4.2 Specific Objectives

The specific objectives of the study are:

1. To evaluate the utility of marble dust powder as a partial replacement of cement in concrete.
2. To determine the optimum percentage of marble dust powder replacing cement to produce effective concrete mix.
3. To compare the performance of conventional concrete with marble dust powder blended concretes.
4. To verify the effectiveness of using marble dust powder in concrete strength enhancement.

1.5 Significance of the Study

The result of the study could have great importance in addressing the environmental problems due to the marble dust powder produced in marble processing factories and in minimizing the emission of CO_2 to the atmosphere as a result of cement production. It may also assist the marble processing industries and marble processing expertise to plan well effective and efficient use of natural resources in the country.

It also believed that the users can grasp the knowledge of how the combination of marble dust powder and Portland cement can be used in concrete and to what percentage it is effective in production of concrete.

Therefore, the result of the study may have environmental, economic and technical advantages upon successful utilization of marble dust powder in concrete.

1.6 Scope of the Research

In the first glance, the research was cover conducting tests on physical properties of concrete making materials such as fineness of cement and marble dust powder, silt content of fine aggregate,(moisture content, unit weight, gradation, specific gravity and water absorption) of fine and coarse aggregates which are most basic in concrete mix design.

The research work was then extent to studying on consistency and setting time of blended pastes, workability of fresh concrete,(density, compressive strength, flexural strength, split tensile strength and water permeability) of hardened concrete produced using marble dust powder blended cement.

1.7 Limitation of the Research

Ordinary Portland cement (OPC) was used throughout the experiment in production of normal C-25 concrete and blended concretes. The reason to select only one type of cement and only one grade of concrete is due to financial and time limitation to perform experiments.

Only some basic properties of cements were tested due to lack of basic laboratory instruments such as Le Chatelier apparatus for soundness test, Muffle furnace for loss on ignition test and Blaine (air permeability) apparatus for fineness test etc. in the laboratory.

Lack of standard mixer and table vibrator for concrete mixing and casting were also another limitation during the research.

1.8 Organization of the Research

Research writing is the final step of the study and it contains five main chapters which are organized in such a way that it can systematically convey the works undertaken and be clear and consistent in flow simultaneously, so that the reader can easily grasp the required targets. These are the introduction, literature review, materials used for research and methodologies, test results and discussions, and conclusion and recommendations.

Chapter One: Introduction: This chapter comprised the background of the study, statement of problem, research questions, research objectives, significance of the study, scope of the research, organization of the research and some limitations during the study.

Chapter Two: Literature Review: The literature review started with exploration of previous studies and theories related to the research in answering the research questions and achieving research objectives.

Chapter Three: Materials and Methodologies: This chapter discussed on the materials used in the research with their source and physical properties; as well as techniques used in conducting the laboratory experiments.

Chapter Four: Results and Discussions: In this chapter, based on the results of laboratory investigations, the influence of marble dust powder has on the properties of cement paste and concrete are discussed in detail.

Chapter Five: Conclusion and Recommendations: This is the final chapter of the research in which conclusions and recommendations were drawn based upon the laboratory test results, linking them to the problem statement, research questions and objectives of research.

CHAPTER TWO

LITURETURE REVIEW

2.1 Background

Sustainable Concrete is the need of the hour. Production of concrete with waste material as alternative ingredient reduces the overall carbon footprint of the manufactured concrete by addressing the problem of efficient waste disposal. For the past few years researchers have been struggling hard to ascertain the feasibility of a wide range of industrial byproducts like rubber, fly ash, coal bottom ash, blast furnace slag, and marble waste as a potential substitute for concrete ingredients. It is concluded that the concrete with marble waste performed satisfactorily on mechanical strength requirements (Hamza et al., 2011; Demirel Bahar et al., 2010; Almeida et al., 2007; Alzboon and Mahasneh et al., 2009).

With more and more economies undergoing massive globalization in the present context the pace of consumption of natural resources and subsequently the rate of scrap generation is on an all-time high in all sectors of manufacturing industries. Construction industry is not an exception to this trend. Over the years the consumption of concrete throughout the world has reached mind boggling scales. A study published by Berkeley University (2015) showed that the annual global consumption of concrete is about 11.5 billion tons including 1.5 billion ton of cement, 1 billion ton of water and 9 billion ton of aggregate. This generates about 1.5 billion ton of CO_2 which accounts for almost 5% of the total CO_2 production in the world. This by any means is a serious threat to the environment and demands immediate attention.

Marble dust powder is one of these by-product materials found from marble process factories. Recently it has been studied for its feasibility as a cement replacing material in some parts of the world and has been found to improve some of the properties of concrete. The performance of concrete is assessed by different tests on both the fresh and hardened concrete. These include workability, strength and permeability.

This chapter is therefore, more of in discussing about cement; cement pastes, different performance of concrete, and use of marble dust powder in concrete.

2.2 Portland cement

Portland cement is the chief ingredient in cement paste-the binding agent in Portland cement concrete (PCC). It is a hydraulic cement that, when combined with water, hardens into a solid mass. Interspersed in an aggregate matrix it forms PCC. As a material, Portland cement has been used for well over 175 years and, from an empirical perspective, its behavior is well understood. The patent for Portland cement was obtained in 1824 by Joseph Aspdin. Chemically, however, Portland cement is a complex substance whose mechanisms and interactions have yet to be fully defined. The Portland Cement Association (PCA) provides the following precise definitions:

Hydraulic cement: Hydraulic binder, i.e. a finely ground inorganic material, which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes and which, after hardening, retains its strength and stability even under water.
Portland cement: Hydraulic cement composed primarily of hydraulic calcium silicates.

Today, Portland cement is the most widely used building material in the world with about 1.56 billion tones (1.72 billion tons) produced each year. Annual global production of Portland cement concrete hovers around 3.8 million cubic meters (5 billion cubic yards) per year (Cement Association of Canada, 2004).

2.2.1 Chemical Composition of Portland cement

Portland cements can be characterized by their chemical composition although they rarely are for pavement applications. However, it is a Portland cement's chemical properties that determine its physical properties and how it cures. Therefore, a basic understanding of Portland cement chemistry can help one understand how and why it behaves as it does. On the basis of quantity, the constituents of Portland cement can be categorized into:

- Major constituents
- Minor constituents

The composition of Portland cements is what distinguishes one type of cement from another. The major constituents in Portland cement are denoted as tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF). The actual components are often complex chemical crystalline and amorphous structures, denoted by cement chemists as "elite" (C_3S), "belite" (C_2S), and various forms of aluminates. Tricalcium silicate and dicalcium silicate, significantly, contribute to the strength of hydrated cement paste. The roles of tricalcium aluminate and tetracalcium aluminoferrite in strength development are controversial (Bogue, 1955).

Tricalcium aluminate contributes to flash setting. However, gypsum retards this effect, allowing tricalcium silicate set first. Otherwise a rather porous calcium aluminate hydrate would form, providing the remaining cement compounds a porous framework for hydration–adversely affecting the strength of the cement paste (Taylor, 1990).

The behavior of each type of cement depends on the content of these components. Main Constituents in a typical Portland cement is exhibited in table 2.1.

Table 2.1 Main Constituents in a typical Portland cement (Taylor, 1990).

Chemical Name	Chemical Formula	Shorthand Notation
Tricalcium Silicate	$3CaO.SiO_2$	C_3S
Dicalcium Silicate	$2CaO.SiO_2$	C_2S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium Aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF
Gypsum	$CaSO_4.H_2O$	CSH_2

2.2.2 Hydration of cement

The development of microstructure of concrete is closely related to hydration of the cement. Hydration is the chemical combination of the different compounds in cement with water to form new compounds which, as time goes on, produce a firm and hard mass - the hardened cement paste. Although cement hydrates faster initially, the rate of hydration of cement decreases continuously so that even after a long time, appreciable amount of unhydrated cement remains in the concrete. Moreover, hardening of concrete will hardly continue after having been interrupted once and therefore, curing measures must start immediately after casting and should never be interrupted (Neville and Brooks, 2003; Steven H. et al, 2002).

The two calcium silicates, C3S and C2S, which are the main cementitious compounds in cement, hydrate to form the compounds calcium hydroxide and calcium silicate hydrate (previously called tobermorite gel). Hydrated Portland cement contains 15% to 25% calcium hydroxide and about 50% calcium silicate hydrate by mass. It is the calcium silicate hydrate that primarily determines the strength and other properties of hydrated cement. C3A reacts with water so rapidly that it leads to flash set, which is actually prevented by adding gypsum to the cement clinker. It thus reacts with water and calcium hydroxide to form tetracalcium aluminate hydrate. And C4AF reacts with water to form calcium aluminoferrite hydrate. Hydration of cement is a complicated process and these reactions represent only the basic compound transformations. They are summarized in Table 2.2, and Figure 2.1 shows estimates of the relative volumes of the compounds in hydrated Portland cement pastes(Steven H. et al, 2002).

Table 2.2 Portland cement compounds hydration reactions (Steven H. et al, 2002).

$2(3CaO.SiO_2)$ Tricalcium silicate	+11H2O Water	= 3CaO.2SiO2.8H2O Calcium silicate hydrate (C-S-H)	+ 3(CaO.H2O) Calcium hydroxide
$2(CaO.SiO_2)$ Dicalcium silicate	+ 9H2O Water	= 3CaO.2SiO2.8H2O Calcium silicate hydrate (C-S-H)	+ CaO.H2O Calcium hydroxide
$3CaO.Al_2O_3$ Tricalcium Aluminate	$+3(CaO.SO3.2H_2O)$ Gypsum	+26H2O Water	= 6CaO.Al2O3.3SO3.32H2O Ettringite
$2(3CaO.Al_2O_3)$ Tricalcium aluminate	$+6CaO.Al_2O_3.3SO_3.$ $32H_2$ Ettringite	+ 4H2O Water	= 3(4CaO.Al2O3.SO3.12H2O Calcium monosulpho aluminate
$3CaO.Al_2O_3$ Tricalcium aluminate	+ CaO.H2O Calcium hydroxide	+ 12H2O Water	= 4CaO.Al2O3.13H2O Tetracalcium aluminate hydrate
$4CaO.Al_2O_3.Fe_2O_3$ Tetracalcium aluminoferrite	+ 10H2O Water	+ 2(CaO.H2O) Calcium hydroxide	$= 6CaO.Al2O3.Fe2O3.12H_2O$ Calcium aluminoferrite hydrate

Hydration of cement compounds is an exothermic reaction and the quantity of heat evolved upon complete hydration at a given temperature and per unit gram of unhydrated cement is called the heat of hydration. For the usual range of Portland cements, about one half of the total heat is liberated between 1 and 3 days, about three quarters in 7 days, and nearly 90% in 6 months (Neville and Brooks, 2003). It has to be noted that fineness of cement affects the rate of heat development but not the total amount of heat liberated, which can therefore be controlled by the quantity of cement in the concrete mix. In general, by reducing the proportions of C3A and C3S in cement, it is possible to reduce the rate as well as the total heat of hydration.

2.2.3 Fineness of Port land cement

The last step in manufacturing Portland cement involves grinding of Portland cement clinker with calcium sulfate or one of its hydrates. The product of this grinding stage is known as Portland cement. The fineness to which cement is ground has a significant effect on the behavior of cement, especially during the early stages of hydration (Mindess et al., 2003).

For cements, there are two basic measures of fineness; namely, Blaine (air permeability) and Turbidimetery. Blaine fineness is an indirect measure of the total surface area of each cement sample and can be determined by the air permeability apparatus according to ASTM C204-11. While the method is widely used in the cement industry for quality control, it offers some drawbacks. For example, a single averaged value may be given to two cements with different proportion of fines; that is, two different cements having the same surface area can give the same Blaine value even though they have very different particle size distributions (Mehta and Monteiro, 1993).

Also, for the same specific surface area, two cements of significantly different particle size distribution will have different water demands. A higher proportion of fines would also indicate a higher early strength gain (Mehta and Monteiro, 1993). In terms of strength gain, the effect of fineness is more pronounced on early age strength than on the ultimate strength (Bentz and Haecker, 1999).

Particle size distribution (PSD) defines the relative amount of particles at specific sizes or size ranges. Typically, particle sizes of Portland cements vary from $<1\mu m$ to $100\mu m$ in diameter (Mehta and Monteiro, 1993). Moreover, PSD affects fresh and hardened concrete properties (Bentz and Haecker, 1999). It has been reported that a wider size distribution increases the packing density of the system and effectively reduces water demand (Wang, et al., 1999).Consequently, it is expected that increasing the packing density would have a positive contribution to strength gain potential. The effect of fineness is also extended to the amount of heat generated by Portland cement, which increases with increasing fineness (Mehta and Monteiro, 1993).

2.2.4 Consistency of cement paste

Many of the properties of concrete are affected by its water content. The physical requirements of cement paste like setting and soundness depends on the water content of the neat cement paste. Therefore it is necessary to define and study the water content at which to do these tests. This is defined in terms of the normal consistency of the paste which is measured according to ASTM C 187.

The amount of water required to achieve a normal consistency as defined by a penetration of 10 ± 1 mm of the Vicat plunger (ASTM C 187) is expressed as a percentage by weight of the dry cement, the usual range being about 26% to 33% (Dinku, 2002). The test is very sensitive to the conditions under which it is being carried out, particularly the temperature and the way the cement is compacted into the mold.

2.2.5 Setting time of cement paste

Setting is defined as change of cement paste from a fluid to a rigid state. It occurs as a result of the hydration of cement compounds. Cement paste setting time is affected by cement fineness, water-cement ratio and chemical content. Setting tests are applied to characterize how a cement paste sets.

Normally, two setting times are defined (Mindess and Young, 1981):

1. **Initial set.** Occurs when the paste begins to stiffen considerably.
2. **Final set.** Occurs when the cement has hardened to the point at which it can sustain some load.

According to Peter Hewlett (2004), setting is a process in which cementations mixtures of plastic consistency is converted into a set material which has lost its deformability and crumbles under the effect of sufficiently great external force. It is preceded by a stiffening of the paste in which the apparent viscosity of the material increases without losing its plastic character. There are two types of setting time i.e. initial and final setting times. The initial setting time indicates the time at which the paste begins to stiffen considerably and can no longer be molded; while the final setting time indicates the time at which the paste has hardened to the point at which it can sustain some load. Like normal consistency these tests are also used for quality control.

Ethiopian standard recommends that the initial setting time for cement not to be less than 45 minutes and the final setting time not to exceed 10 hours (Dinku, 2002).

2.3 Use of marble dust powder in concrete

The effect of marble dust powder and blended cement on properties of concrete has been studied extensively and a majority of findings are in favor of a better improvement of hardened concrete properties such as compressive strength, flexural strength, tensile split strength, and some other properties of the concrete. Such improvements in the properties of concrete are due to suitable texture fineness and particle size distribution of cement containing marble dust powder.

Aliabdo et al (2014) investigated the possibility of utilizing waste marble dust (MD) in cement and concrete production by discussing the properties of concrete contained marble dust as a cement replacement and as a sand replacement (cement addition). The replacement ratios which have been studied were 0.0%, 5.0%, 7.5%, 10% and 15% by weight. Water to cement ratio (w/c) were 0.50 and 0.40 in case of cement replacement and in case of sand replacement, respectively. It was observed that the higher values of marble dust decreases the C3A content compared to plain cement. For 15% marble dust, there was a decrease of 10% in the compressive strength of concrete. At w/c of 0.5, in all levels of marble dust as a cement replacement, the concrete compressive strength slightly decreases. Most likely this is due to the reduction in cementing material (C3A and C2S) which is mainly responsible for concrete strength. But at the w/c of 0.4 there was slightly increase up to the 10% MD. This could be due to the pore-filling effect of fine marble dust that enhances the properties of the transition zone surrounding aggregate.

Pathan, et al (2014), studied the Feasibility and Need of use of Waste Marble Powder in Concrete Production. This paper presents the feasibility of the substitution of marble waste for cement to achieve economy and environment saving. In this paper, only some basic study of using marble waste in cement and concrete production is investigated. They concluded that the marble dust can be used as a replacement for cement. Test results indicate that the 10% of marble dust in the cement concrete gives the best results. And also increase in curing days will increase the strength of marble dust concrete when compared from 14 days to 28 days.

Pathan and Pathan (2014) studied the feasibility of the substitution of marble dust for cement to achieve economy and environment saving. They reviewed different literature and concluded that in concrete production replacement of 5% cement by marble waste powder gives comparable compressive and flexural strength as of control concrete specimens; but increasing the replacement range beyond 5% results in strength reduction. In concrete production, replacing of sand up to 20% by marble waste powder gives similar strength as of concrete mixes with 100% sand both at early and latter ages.

On the basis of the earlier experimental studies the unit weight of the concrete increased due to the high specific gravity of WMD and also filler effect of marble dust because it has finer particles than fine sand aggregate. As a matter of fact marble dust had a filler effect (particularly important at early ages) and played a noticeable role in the hydration process. Cement being kept constant it is an expected outcome that an enhancement in the mechanical and physical properties has taken place by virtue of the marble dust's contribution to the hydration process (Pathan and Pathan, 2014).

Prof. P.A. Shirule et al (2012), The Compressive strength of Cubes and Split Tensile strength of Cylinders are increased with addition of waste marble powder up to 10% replace by weight of cement and further any addition of waste marble powder the compressive strength and Split Tensile strength of Cylinders decreases. Thus they found out the optimum percentage for replacement of marble powder with cement and it is almost 10% of the total cement for both cubes and cylinders.

2.4 Properties of Concrete

Concrete is the most commonly used modern construction materials. It forms the basis of the modern construction system. Many of our activities directly or indirectly are affected by concrete structures; the buildings we live and work in, the roads we drive on, the dams from which we get water and energy, etc. can be an example. The ability of concrete to be cast into any desired shapes and configurations is the reason for its versatility (Hailu, 2011).

The word concrete comes from a Latin word concretus which means to grow together (Mindess et.al, 2003), which implies that it is a composite of different materials. It is composed of coarse granular material called aggregate or filler which is embedded in a hard matrix of material (cement or binder with water) binding the aggregates together and filling the space formed between them. When the constituents are mixed with water the concrete solidifies and hardens due to a chemical reaction between the water and the cement called hydration, which finally forms a stone like material by binding the aggregates together.

Concrete is mainly composed of cement, aggregate and water. Cementitious materials, pozzolanic materials, filler materials, chemical admixtures, and some other additives may also be the constituents of concrete depending on the need and their availability. All the constituents have their own purpose in the concrete. Cement with water acts as a binding medium in which the aggregates which accounts 70% to 80% of the concrete are bound together to form the concrete. Economy, dimensional stability and wear resistance are the main reasons behind using aggregates. Different types of admixtures are used to modify the properties of ordinary concrete so as to make it suitable for any situation (Hailu, 2011).

According to (Hailu, 2011) a concrete is to be suitable for a particular purpose, it is necessary to select the constituent materials and combine them in such a manner as to develop the special qualities required as economical as possible. Therefore the selection of constituents of concrete depends on the quality and economy of the particular concrete required.

2.4.1 Workability of concrete

This term is defined in ASTM C 125 as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity. The term manipulate includes the operations of placing, compacting and finishing the concrete.

Neville and Brooks (1987), on the other hand define workability as the amount of useful internal work necessary to produce full compaction. They note that the useful internal work is a physical property of the concrete alone, but they note there is additional energy required to overcome friction between the concrete and the formwork and the reinforcement as well as the energy required to vibrate the formwork, the reinforcement, and the concrete which has already been compacted.

Mindess et.al (2003), workability is the measure of how easy or difficult it is to place, consolidate and finish concrete. It contains in it different aspects like consistency, flow ability, mobility, compact-ability, finish-ability, and harshness. It can also be defined in terms of the amount of mechanical work, or energy required producing full compaction of the concrete without segregation. This property of concrete is affected by a number of factors like: water content of the mix, mix proportions, aggregate properties, time, temperature, characteristics of the cement and admixtures.

Water content is the most important factor affecting the workability of concrete. Increasing the amount of water will increase the workability of the concrete. However the increase in water content of the mix will decrease the strength and also result in segregation and bleeding (Hailu, 2011).

When considering the effect of aggregate the amount of aggregate, the proportion of coarse and fine aggregate and the shape and texture of the aggregate particles affect the workability of concrete. Keeping the water content and cement content constant increasing the amount of aggregate reduces the workability of concrete. Spherical and smooth aggregate result in a more workable mix, whereas flat, elongated and rough aggregate particles will result in reduction of workability. The increase in the ambient temperature will reduce the workability of the concrete, due to increase of evaporation and rate of hydration caused by the higher temperature (Hailu, 2011).

The cement content and cement replacing materials also affect the workability. Higher cement content reduces workability. The effect of cement replacing materials depends on their nature. Finer materials result in reduction of workability while spherical materials increase it (Hailu, 2011).

2.4.2 Strength of concrete

Strength of concrete is commonly considered its most valuable property, although in many practical cases other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because it is directly related to the structure of the hardened cement paste (Neville, 1994).

The strength of concrete is dependent on many things. The hydration reaction, water to Cement ratio, aggregate type, amount and size, water content, cement content, curing condition, cement type, compaction method used etc. have an effect on the strength of concrete. Strength at any w/c ratio depends on the degree of hydration of the cement and its physical and chemical properties. The decrease in the water content of the concrete results in a higher strength of the concrete. The water required for the hydration reaction is less than that of the mixing water; the extra water provided is used to make the concrete more workable. The compaction of the fresh concrete reduces the amount of entrapped air and therefore increases the strength of the concrete. It is found that for each 1% of air entrapped there will be a 5 to 6% loss on strength (G/Egziabher, 2005). Curing temperature affects the hydration of cement and hence the duration of strength gains. Cubes kept at about $10^{o}C$ will have their 7 day strength reduced by 30% and their 28 day strength by 15%.

2.4.3 Durability of concrete

Sushi Kumar (2009) define as durability is the property of concrete by virtue of which it is capable of resisting its disintegration and decay which may be caused due to: use of unsound cement, use of less durable aggregate, entry of harmful gases and salts through the pores and voids present in the concrete, freezing and thawing of water sucked through the cracks or crevices by capillary action, expansion and contraction resulting from temperature changes and alternate drying and wetting.

Sushi Kumar (2009) states that durability of concrete depends mostly upon conditions of exposure, grade of concrete used, quality of its materials and the extent of voids and pores present in the concrete mass. The amount of cover provided over reinforcement and the degree of imperviousness of concrete mix also influence the durability of concrete.

The durability of concrete is a function of permeability. Hence concrete can be made durable by using good quality of materials by reducing the extent of voids by suitable grading and proportioning the materials, using adequate quantity of cement and low water cement ratio there by ensuring permeability (Sushi Kumar, 2009). Cement replacing materials can play role in reducing the extent of voids in concrete which in turn improves permeability of concrete.

2.4.4 Permeability of concrete

The movement of fluid through a porous medium due to a pressure head difference is called permeability. Thus ability of the concrete to transmit fluids through it caused by pressure head difference is called permeability of concrete. This term applies to both gases and liquids (Bogale, 2007). This property of concrete plays a great role in the durability of the concrete because it controls the entry of moistures which may contain aggressive chemicals and the movement of water during heating and freezing. Durability of concrete refers to the ability of concrete to resist weathering actions, chemical attacks, abrasions or any processes of deteriorations.

The water to cement ratio (w/c) of concrete has major influence on the permeability of concrete. As the w/c ratio decreases the porosity of the paste decrease and the concrete becomes more impermeable. This variation of permeability with w/c ratio is largely due to large capillary porosity rather than gel pores. Most pozzolanic materials were found to decrease the permeability of concrete due to the pozzolanic reaction and their higher fineness. The pozzolanic reaction consumes the free lime in the concrete and the higher fineness of the pozzolan fills pores in the concrete both resulting in a lower permeability.

Tests to measure permeability usually fall into three categories (Mindess, 2003).Two of them involve the movement of water through concrete, while the third one involves the movement of electric charge. Here the gas and water permeability are discussed.

2.4.4.1 Water permeability of concrete

Among the fluids penetrating concrete water is the most important one. This property of concrete is not a simple function of its porosity, but depends also on the size, distribution, shape and continuity of the pores. According to Neville (1994), although the cement gel has a porosity of 28 percent, its permeability is only about $7x10^{-16}$m/s. The reason as explained in Neville is due to the extremely fine texture of hardened cement paste: the pores and the solid particles are very small and numerous, whereas, in rocks, the pores, though fewer in number, are much larger and lead to a higher permeability.

The progress of hydration affects the permeability of concrete. In a fresh paste the size, shape and concentration of the unhydrated cement particles controls the permeability. As hydration proceeds the permeability decreases rapidly because the gross volume of gel is approximately 2.1 times the volume of unhydrated cement, so that the gel gradually fills some of the original water-filled space (Neville, 1994).

The water/cement ratio of the concrete greatly affects the permeability of concrete. The reduction in the coefficient of permeability is faster the lower the water/cement ratio of the paste. For cement pastes hydrated to the same degree, the permeability is lower the higher the cement content of the paste. Moreover, increasing the wet curing duration of concrete with a very high water/cement ratio from 1 day to 7 days reduces its water permeability by a factor of 5 (Neville, 1994).

Two types of water permeability methods are used to measure the penetration of water into concrete. These are the steady state water permeability and the non-steady state water permeability. In the case of steady state, water is allowed to move across the specimen until steady state flow is attained. The penetrated water is recorded when the flow of water becomes steady. The Darcy’s law is used to find the coefficient of permeability. In the case of non-steady state, the depth of water penetration is measured without the water flow necessarily reaching a constant value. A succession of water is applied across the specimen as follows (Bogale, 2007):

- 3Bar (0.3MPa) for the first 24 hours,
- 5Bar (0.5MPa) for the next 24 hours, and
- 7Bar (0.7MPa) for the last 24 hour.

At the end of the 72 hours period, the specimens will be removed from the rig and split at the center. Just after splitting, the maximum and average depths of penetration are visually observed and measured at a desired spacing (Desta S. K., 2000).

2.4.4.2 Gas permeability of concrete

The coefficient of permeability of gases is affected by viscosity and compressibility of the gas. For the case of laminar flow (flow of fluids in parallel layers with no disruption between the layers), the coefficient of permeability is given by equation 2.1(Bogale, 2007):

$$\text{Kg} = \eta * \frac{QL}{A} * \frac{2P}{(P1 - P2)(P1 + P2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{[Eq. 2.1]}$$

Where: K_g = coefficient of permeability (m^2)

η = viscosity of the gas (Ns/m^2)

Q = volume of gas flowing (m^3)

l = thickness of penetrated section (m)

A = penetrated area (m^2)

p = pressure at which volume Q is measured (N/mm^2)

p_1= pressure at entry of gas (N/m^2)

p_2 = pressure at exit of gas (N/m^2)

t = time (s)

Due to the wide range of pore diameters, the condition of laminar flow may not necessarily prevail for the transport of gases through the paste of concrete. For this reason the coefficient of gas permeability has also been defined as shown in equation 2.2. In this case, Kg is no longer a material characteristic but depends on the transport medium.

$$\text{Kg} = \frac{Q}{t} x \frac{L}{A} x \frac{P}{P1 - P2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{[Eq. 2.2]}$$

Where, K_g= coefficient of permeability (m^2/s).

CHAPTER THREE

MATERIALS AND METHODOLOGIES

3.1 Introduction

In this chapter, the materials used for the research are described with respect to their source and relevant physical properties. All the laboratory investigations on the aggregates, fineness of cement and marble dust powder, blended pastes, and concretes were carried out in Jimma University, Civil Engineering Department, Construction Material Laboratory; whereas the water permeability test of concrete was conducted in Addis Ababa University Institute of Technology.

3.2 Marble dust powder

The marble dust powder used for this research was collected from Ethio-marble Processing Enterprise which is located in Addis Ababa, Gulale sub-city. The marble dust powder in this factory is existed in two forms. The water used during polishing and cutting process has carried these dust particles in the form of slurry and discharged into container prepared for this purpose. After collected in the container, it is removed, dumped out as waste and gets dried. The other marble dust powder is obtained after grinding of broken marbles collected in the company. This solid waste is coarser whereas the former is finer. For the purpose of maintaining comparable fineness with Portland cement, the powders were mixed 50% by weight from both types of wastes after sieved through 100μm sieve size.

Figure 3.1 Marble dust powder used in the research

3.3 Cement

In this research work, the Ordinary Portland Cement, Dangote 3X class of strength 42.5R was used. The Dangote 3X cement 42.5R is manufactured by the Dangote Cement Manufacturing Company. The sample was acquired from a local dealer Al-Mersu, which located in Merkato, Jimma, Ethiopia. Some tests were conducted related to its normal consistency, setting time and some physical properties which are discussed in the next chapter of this research.

Figure 3.2 Dangote 3x Ordinary Portland cement (OPC) used in the research

3.4 Properties of Fine Aggregate

Normal river sand commonly known as Gambella sand, which is extracted from Baro is found in Gambella region about 5km from Gambela town, was used to prepare the concrete samples. Since, the aggregate is extracted from the river side; it's full of dust film on their surface. For this reason, the fine aggregates were washed thoroughly and dried in the air outside the laboratory to saturated surface dry (SSD) state before any test was carried out. Figure 3.3 below shows Gambella sand used in the research while under drying in the air after washed.

Figure 3.3 Gambella sand used in the research while under drying in the air after washed.

All fine aggregate which retain on 9.5mm sieve size were no longer used, and only the passing fine aggregate were used for experimentation. Any test related to physical property of fine aggregates has been discussed as below.

3.4.1 Silt Content of Fine Aggregate

The material in fine aggregates which is finer than 75μm is generally regarded as silt. This silt in the sand for the concrete has a severe effect on the quality of the concrete. It mainly affects the workability of the concrete, and also results in the reduction of strength.

From the silt content test performed on the sand, it was found that the original silt content was 6.57%. The Ethiopian standard restricts the silt content to a maximum of 6%. If it exceeds this maximum value the standard recommends either washing or rejecting the sand. Therefore the sand was washed and its final silt content was minimized to 3.63%.

3.4.2 Gradation and Fineness Modules for Fine Aggregate

This is a procedure for the determination of the particle size distribution of the aggregate. It is also used to determine the fineness modulus, an index to the fineness, coarseness and uniformity of aggregates. These properties of the aggregate greatly affect the property of the concrete.

The Gambela sand used in this research satisfies the Ethiopian standards ES C.D3.201 requirements and the grain size distribution of the sample sand is as shown in Table 3.1 and Figure 3.4 below.

Table 3.1 Sieve analysis test result and standard requirement for fine aggregate

Sieve size	Cumulative Passing (%) ES C.D3.201	Cumulative Passing (%) (Sample sand)
9.5 mm	100	100
4.75 mm	95-100	96
2.36 mm	80-100	88
1.18 mm	50-85	71
600 µm	25-60	50
300 µm	10-30	19
150 µm	2-10	6

The graph below shows the comparison between gradation of sample sand and the Ethiopia standard ES C.D3.201.

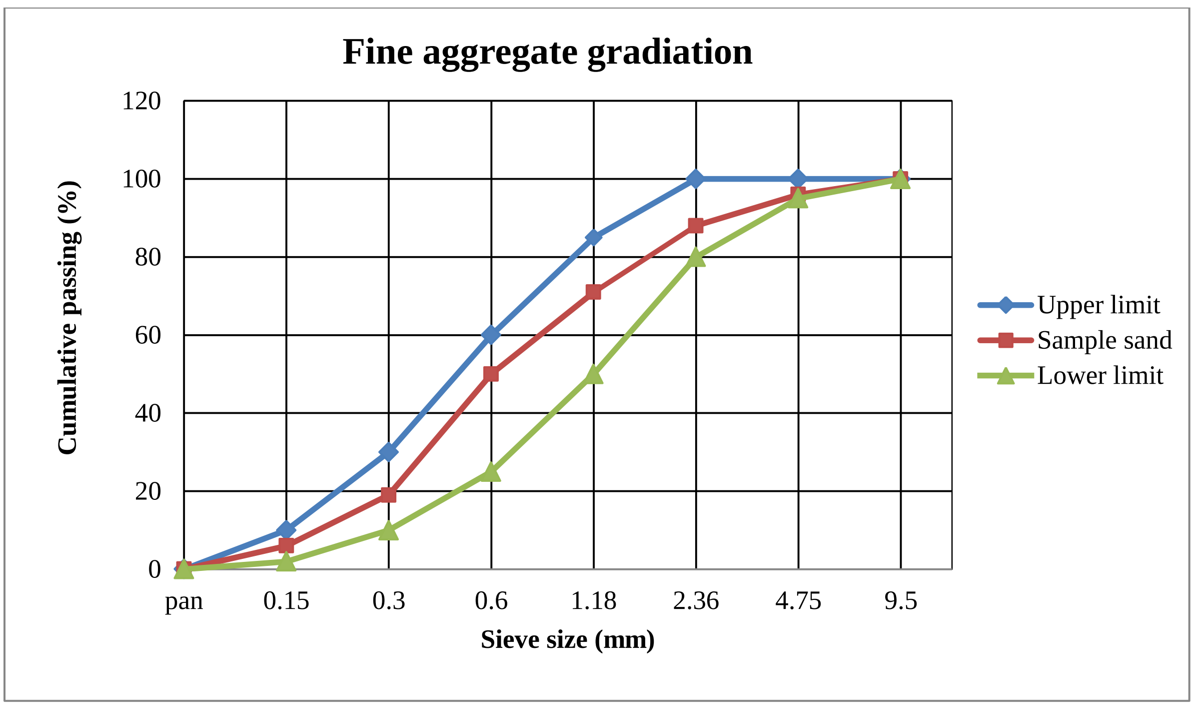

Figure 3.4 Graph for gradation of fine aggregate

$$\text{Fineness Modules} = \sum \frac{\text{cumulative coarser (\%)}}{100} = \frac{270}{100} = 2.70$$

The coarser the aggregate size, the higher the FM. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 as called for in ASTM C 33. However, depending upon their size, sand can be classified as coarse sand when a fineness modulus is between 2.90 to 3.20; medium sand with a fineness modulus of 2.60 to 2.90 and; fine sand with a fineness Modulus of 2.20 to 2.60 (Neville, 1996).

Therefore, sieve analysis result shows that the Gambella sand used in this research is categorized as medium sand.

3.4.3 Specific Gravity and Water Absorption Capacity of Fine Aggregate

Specific gravity is an expression of the density of an aggregate. It is the ratio between the weight of the substance and that of the same volume of water. Aggregates contain pores in their structure, therefore the specific gravity depends on whether the pores are included in the measurement or not. Apparent specific gravity of an aggregate refers to the solid materials excluding the pores and bulk specific gravity refers to total volume i.e. including pores of the aggregate.

Absorption capacity of the aggregate is computed as a percentage by subtracting the oven-dry mass from the saturated surface-dry mass, dividing by the oven-dry mass, and multiplying by 100. In concrete technology, aggregate moisture is expressed as a percent of the dry weight of the aggregate (ACI Committee, 2007).

Table: 3.2 Specific gravity and water absorption of fine aggregate observation sheet

S.No	Description		Sample I	Sample II
1	Weight of sample		2000	2000
2	Weight of saturated & surface dry sample (C) g		500	500
3	Weight of pycnometer + sample + water (A), g		1947	1955
4	Weight of pycnometer + water (B), g		1650	1650
5	Weight of oven dry sample (D), g		495	496
6	Specific gravity = $\left[\frac{D}{C-(A-B)}\right] * 100$		2.44	2.54
7	Apparent specific gravity = $\left[\frac{D}{D-(A-B)}\right] * 100$		2.50	2.60
8	Water absorption capacity = $\left[\frac{C-D}{D}\right] * 100$, %		1.01	0.80
9	Average values	Specific gravity	2.49	
		App. specific gravity	2.55	
		Water absorption	0.91 %	

3.4.4 Moisture content of fine aggregate

The water to cement ratio of a concrete affects the strength and the workability of the concrete. The increase of the water to cement ratio results in a decrease of the strength of the concrete and an increase of workability. The aggregates in concrete are assumed to be inert materials. But most of the aggregates don't meet this assumption by either absorbing water (dry aggregates) or by releasing it (wet aggregates) to the mix. As a result of this property of aggregates the design water to cement ratio of the mix changes. In order to correct for these discrepancies, the moisture content of aggregates has to be determined (Dinku, 2002). Therefore it is important to determine both the absorption capacity and the moisture content of the aggregate.

The moisture content of fine aggregates was determined by oven drying a sample of fine aggregate (500gm) in an oven at a temperature of 110 0c for 24hrs and dividing the weight difference by the oven dry weight. The average moisture content found was 1.01% as described in table 4.3 below.

Table 3.3 Test on moisture content of fine aggregate

S.No	Description	Sample I	Sample II
1	Weight of sample (A), g	500	500
2	Weight of oven dry sample (B), g	494	496
3	Moisture content = $\left[\frac{A-B}{B}\right]$*100	1.21%	0.81%
4	Average moisture content of fine aggregate	**1.01%**	

3.4.5 Unit weight of fine Aggregate

Unit weight can be defined as the weight of a given volume of graded aggregate. It is thus a density measurement and is also known as bulk density. But this alternative term is similar to bulk specific gravity, which is quite a different quantity, and perhaps is not a good choice.

The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. The unit weight is simply measured by filling a container of known volume and weighing it. Clearly, however, the degree of compaction will change the amount of void space, and hence the value of the unit weight. Since the weight of the aggregate is dependent on the moisture content of the aggregate, constant moisture content is required. Oven dried aggregate sample is used in this test (Dinku, 2002). The unit weight of the fine aggregate sample used was found to be 1490kg/m^3 as summarized in table 3.4 below.

Table 3.4 Test on unit weight of fine aggregate

S.No	Description	Sample I	Sample II
1	Weight of container (A), Kg	1.065	1.065
2	Weight of container + Weight of Aggregate (B), Kg	8.540	8.490
3	Volume of container (C) m^3	0.005	0.005
4	Unit weight of Aggregate = $\left[\frac{B-A}{C}\right]$, kg/m^3	1495	1485
5	Average unit weight of coarse aggregate	**1490 kg/m^3**	

3.5 Properties of Coarse Aggregate

The coarse aggregate used for this research was basaltic crushed rock from china crusher which is located in Agaro. From physical observation, the aggregate came from the crusher site was a fresh and has no dust or impurities on their surface and therefore stored for a while in the laboratory.

In a similar manner like the fine aggregate, laboratory tests were carried out to identify the physical properties of the coarse aggregate and discussed as below.

3.5.1 Gradation for Coarse Aggregate

Gradation refers to the particle sizes distribution present in an aggregate sample. The gradation of the sample is determined in accordance with ASTM C 136. A sample of the aggregate is shaken through a series sieves with square openings, nested one above the other in order of their size, with the sieve having the largest openings on top, the one having the smallest openings at the bottom, and a pan underneath to catch material passing the finest sieve(ACI Committee, 2007).

There are several reasons for specifying grading limits and nominal maximum aggregate size; they affect relative aggregate proportions as well as cement and water requirements, workability, pump ability, economy, porosity, shrinkage, and durability of concrete. Variations in grading can seriously affect the uniformity of concrete from batch to batch. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results (Steven H. et al, 2003).

The maximum size of the coarse aggregate also influences the paste requirements of the concrete, and the optimum grading of the coarse aggregate depends on the maximum aggregate size. As defined by ASTM C 125, the maximum size of coarse aggregate is the smallest sieve opening through which the entire sample passes. For this study a maximum size of 19 mm diameter aggregate was used in all the concrete mix.

The grading requirement for coarse aggregate according to ES C.D3.201 and the grain size distribution of the coarse aggregate sample is as shown in Table 3.5 and Figure 3.5.

Table 3.5 Sieve analysis test result and standard requirement for coarse aggregate

Sieve size (mm)	Cumulative passing (%) ES C.D3.201	Cumulative passing (%) (sample coarse aggregate)
37.5	100	100
19	95-100	97.5
12.5	-	65.3
9.5	25-55	37.5
4.75	0-10	6.5

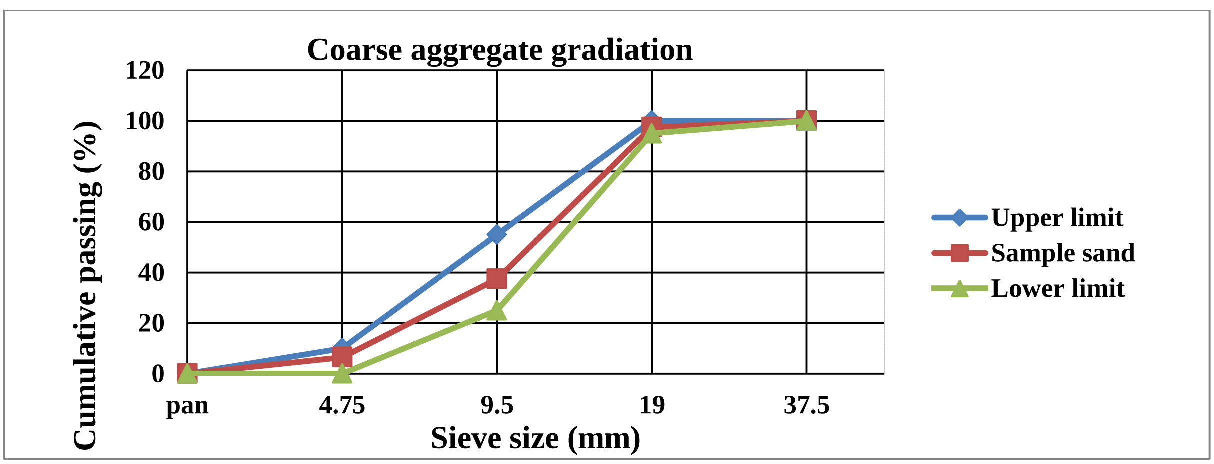

Figure 3.5 Graph for gradation of coarse aggregate

3.5.2 Specific Gravity and Absorption Capacity of Coarse Aggregate

Since aggregates generally contain pores, both permeable and impermeable, the meaning of the term specific gravity has to be carefully defined, and there are indeed different types of specific gravity, like: apparent specific gravity and bulk specific gravity. Bulk specific gravity refers to total volume of the solid including pores of the aggregate, and apparent specific gravity refers to the volume of the solid including the impermeable pores but not the capillary ones. Table 4.6 below shows the experimental procedures.

Table 3.6 Specific gravity and water absorption of coarse aggregate observation sheet

S.No	Description		Sample I	Sample II
1	Weight of sample, g		1000	1000
2	Weight of vessel + sample + water (A), g		2268	2266
3	Weight of vessel + water (B), g		1650	1650
4	Weight of saturated & surface dry sample (C) g		990	992
5	Weight of oven dry sample (D), g		982	984
6	Specific gravity = $\left[\frac{D}{C-(A-B)}\right] * 100$		2.64	2.62
7	Apparent specific gravity = $\left[\frac{D}{D-(A-B)}\right] * 100$		2.70	2.67
8	Water absorption capacity = $\left[\frac{C-D}{D}\right] * 100$, %		0.81	0.81
9	Average values	Specific gravity(SSD)	2.63	
		App. specific gravity	2.70	
		Water absorption, %	0.81	

The bulk specific gravity and apparent specific gravity results obtained from the experiment are 2.63 and 2.70 respectively and, the absorption capacity was found to be 0.81%.

3.5.3 Moisture Content of Coarse Aggregate

Like the fine aggregate, the moisture content of coarse aggregate was determined by oven drying a sample of coarse aggregate (2000gm) in an oven at a temperature of 110 0c for 24hrs and dividing the weight difference by the oven dry weight. The average moisture content found was 0.81% as described in Table 4.7 below.

Table 3.7 Moisture content of coarse aggregate

S.No	Description	Sample I	Sample II
1	Weight of sample (A), g	2000	2000
2	Weight of oven dry sample (B), g	1985	1983
3	Moisture content = $\left[\frac{A-B}{B}\right]$*100, %	0.76	0.86
4	Average moisture content of coarse aggregate, %	**0.81**	

3.5.4 Unit Weight of Coarse Aggregate

The unit weight measurement for coarse aggregate sample was followed the same procedure as in the case of fine aggregate and described in table 4.8 below.

Table 3.8 Unit weight of coarse aggregate

S.No	Description	Sample I	Sample II
1	Weight of container (A), Kg	1.065	1.065
2	Weight of container + Weight of Aggregate (B), Kg	9.290	9.240
3	Volume of container (C) m^3	0.005	0.005
4	Unit weight of Aggregate = $\left[\frac{B-A}{C}\right]$, ($kg/m^3$)	1645	1635
5	Average unit weight of coarse aggregate (**kg/m^3**)	**1640**	

3.6 Water

In this research, tap water supplied by Jimma Institute of technology found around the laboratory area was used throughout the research (for all mixes and curing purpose).

3.7 Experimental Programs I

This experiment consists of determining the fineness of blended powders, the normal consistency and setting time of the blended pastes.

3.7.1 Sample Preparation for Fineness Test

The fineness of cement and the marble dust powders were determined by the sieve analysis method. The sieve analysis method was used to determine the gradation of cement and marble dust powder particles by considering 200gm for each of OPC and MDP samples.

The samples were shaken for 15 minutes through a series sieves with circular openings, nested one above the other in order of their size, with the sieve having the largest (100µm) openings on top, the one having the smallest (32µm) openings at the bottom, and a pan underneath to catch material passing the finest sieve.

Table 3.9 Sieve analysis for marble dust powder and ordinary Portland cement

Sieve Size	Marble Dust Powder (200gm)		Ordinary Portland Cement (200gm)	
	Retained(gm)	Cumulative passing(%)	Retained(gm)	Cumulative passing(%)
100µm	0	100	0	100
90µm	6	97	2	99
75µm	14	90	10	94
63µm	8	86	22	83
32µm	94	39	100	33
pan	78	-	66	-

3.7.2 Sample Preparation for Consistency Test

The vicat needle was used as test method to determine the quantity of mixing water required for preparing cement paste of standard consistency. Standard consistency of a cement paste is defined as that consistency which will permit a vicat plunger having 10mm diameter and 50mm length to penetrate to a depth of 33-35mm from top of the mould.

The mixing was started by adding about 30% water by weight of dry cement to a 400g of cement on the enameled tray to get a cement paste. The mixing was continued for 3 minutes using a hand trowel. Then the cement paste was filled to a standard ring of truncated conical form 40mm deep with internal diameters at top and bottom of 70mm and 80mm respectively. The same procedure was followed for all cement-marble dust powder blended pastes.

Then the mold was completely filled with paste; the surface of the paste was smoothened and leveled using hand trowel. The whole assembly such that mould, cement and glass plate was placed under the rod bearing plunger. The plunger was gently lowered so as to touch the surface of the test block and quickly released to sink into the paste. After thirty seconds release of plunger, the depth of penetration was measured and recorded. The trial was continued by varying the percentage of water by dry weight of cement with fresh trial pastes; until the penetration of plunger reaches 10±1mm below the original surface of the mould. Figure 3.6 displays the vicat procedure.

Figure 3.6 Normal consistency testing (Vicat apparatus)

3.7.3 Sample Preparation for Setting Time Test

The hard rubber mould was in a truncated conical form 40mm deep with internal diameters at top and bottom of 70mm and 80mm respectively as in the case of consistency test. It was provided with a plane glass base-plate larger than the mould with thickness of 2.5mm.

The Vicat needle was used as test method to determine the initial and final setting time of Hydraulic cement, according to EN 196-3 (2005). Figure 3.7 displays the vicat procedure.

Figure 3.7 Setting time testing (Vicat apparatus)

Excess of paste was immediately transferred into the mould in one layer by using hand trowel. The top of the mould was smoothened and leveled. The mould was placed under the initial set needle of cross-sectional area of 1mm and the needle was covered gently onto the surface of the paste and was quickly released by allowing it to sink to the bottom. These tasks were repeated several times at regular intervals of 15 minutes in different positions of mould until the paste has stiffened sufficiently for the needle not to penetrate deeper than 4mm above the bottom of the mould.

The time interval between the addition of water and the initial setting time was recorded. Finally, the needle was replaced with a 1mm square needle fitted with a metal annular attachment and this probe was allowed to come gently with contact with the surface of the cement paste at an interval of 15 minutes. The final set was reached when the needle makes an impression on the surface but annular cutting edges fail to do so.

3.8 Experimental Program II

3.8.1 Mix Design and Material Proportioning

Mix design is the process of determining the required and specified characteristics of a concrete mixture. The required or specified concrete characteristics can be fresh concrete properties, mechanical properties of the hardened concrete such as strength and durability requirements and the inclusion or exclusion of specific ingredients (Steven H. et al, 2003). Mix proportioning on the other hand is the process of determining the quantities of concrete ingredients using local materials to achieve the specified characteristics of the concrete. According to Steven H.et al (2003), a properly proportioned concrete mix should possess the following qualities:

- Acceptable workability of the freshly mixed concrete
- Durability, strength, and uniform appearance of the hardened concrete
- Economy

DOE mix design method was used to proportion the control mixes. I determined target mean strength by considering 5% defectives for which constant K=1.64 and DOE recommended 8N/mm^2 standard deviation in the absence of sufficient data; accordingly 8 N/mm^2 was used. Therefore the margin value of 13N/mm^2 was added to specified characteristic strength.

Concrete without marble dust powder (MDP0) was used as the control mix whereas; MDP4, MDP8, MDP12, MDP16 and MDP20 were prepared to investigate the influence of marble dust powder on concrete properties by replacing it at 4%, 8%, 12%, 16% and 20% percentages by weight of cement respectively.

Table 3.10 Mix proportion for the control and marble dust powder blended concretes.

No	Mix Code	OPC (kg/m3)	MDP (kg/m3)	W/C	Water (kg/m3)	FA (kg/m3)	CA (kg/m^3)
1	MDP 0	340.000	0	0.50	170	624	1266
2	MDP 4	338.824	1.176	0.50	170	624	1266
3	MDP 8	337.647	2.353	0.50	170	624	1266
4	MDP 12	336.471	3.529	0.50	170	624	1266
5	MDP 16	335.294	4.706	0.50	170	624	1266
6	MDP 20	334.118	5.882	0.50	170	624	1266

Where: MDP 0 is a concrete mix with 100% OPC and 0% MDP by weight

MDP 4 is a concrete mix with 96% OPC and 4% MDP by weight

MDP 8 is a concrete mix with 92% OPC and 8% MDP by weight

MDP 12 is a concrete mix with 88% OPC and 12% MDP by weight

MDP 16 is a concrete mix with 84% OPC and 16% MDP by weight

MDP 20 is a concrete mix with 80% OPC and 20% MDP by weight

3.8.2 Concrete Specimen Preparation and Mixing Procedure

As strength is the main quality controlling parameter for concrete, different specimens were prepared for studying the strength. The test specimens for compressive strength and water permeability tests were casted in standard steel mold with 150mmx 150mm x 150mmcubes,rectangular beam of 100mm x 100mm x 500mm for flexural strength and cylinder of 100mm diameter and 200mm height for tensile split strength test. To meet the required quality, simply the preparation of specimens and mixing of the concrete were according to the following procedures:

- **Mixing:** Initially, course and fine aggregate were mixed in dry state until the mixture become homogenous. Then, cement and marble dust powder was added to this dry mixture. Finally, water was added to the dry mixed ingredient and mixing was continued until fresh concrete gets complete homogeneity.

- **Moulding:** The concrete moulds were cleaned from all dust and coated with releasing agent (oil) to smooth the surface and to prevent sticking of mixed concrete with the mold before casting. Then mixed concrete was checked for workability by using the standard slump cone of 300mm high with a bottom diameter of 200mm and top diameter of 100mm size. Then fresh concrete was added to the prepared moulds in three layers according to ASTM C 143.
- **Compacting:** Then mixed concrete was filled into moulds with three layers by rodding each layer 25 times using standard steel tamping rod of 16mm diameter and 600mm long with one end rounded.
- **Demoulding and Curing:** The concrete moulds are kept for 24 hours and then the casted concrete cubes were removed from the mould and stored in water tap.

3.9 Study Variables

3.9.1 Dependent Variable

This variable is the presumed effect in an experimental study. The variable mentioned below is a dependent variable.

- ✓ Utilization of marble dust powder as partial replacement of cement in concrete

3.9.2 Independent Variables

These variables are the presumed cause in an experimental study. The followings are the independent variables:

- ✓ workability of concrete
- ✓ density of concrete
- ✓ compressive strength of concrete
- ✓ flexural strength of concrete
- ✓ tensile split strength of concrete
- ✓ water permeability of concrete

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results and Discussion on Fineness of Marble Dust Powder

The fineness of cement and marble dust powder was determined based on sieve analysis method. The average size of the particle is the sieve size at which 50% of the particles passes, and is determined by linear interpolation. The results of grain size analysis for marble dust powder (MDP) and OPC cement is shown in the table 4.1 below.

Table 4.1 Grain size distribution for marble dust powder (MDP) and OPC cement

Sieve Size	Marble Dust Powder (200gm)	Ordinary Portland Cement (200gm)
	Cumulative Passing (%)	Cumulative Passing (%)
100µm	100	100
90µm	97	99
75µm	90	94
63µm	86	83
32µm	39	33

From the result of particle size analysis, all particles of Ordinary Portland cement and marble dust powder passed through 100µm sieve size. This shows that the particle size for both ordinary Portland cement and marble dust powder is less than 100µm. The particles of MDP sample passed through 90µm and 75µm sieve size are 97% and 90%; whereas OPC sample are 99% and 94% respectively. From the result of 90µm and 75µm sieve analysis, marble dust powder is coarser than ordinary Portland cement. On the other hand, the particles passed through 63µm and 32µm were found to be 86% and 39% for MDP; 83% and 33% for OPC respectively. The results obtained from 63µm and 32µm sieve analysis shows that, marble dust powder is finer than ordinary Portland cement. Based on the 90µm, 75µm, 63µm and 32µm, sieve analysis results marble dust powder is coarser than the cement for higher sieve sizes and the finer for lower sieve sizes than ordinary Portland cement. Therefore, the average size of particles will determine the fineness of these samples.

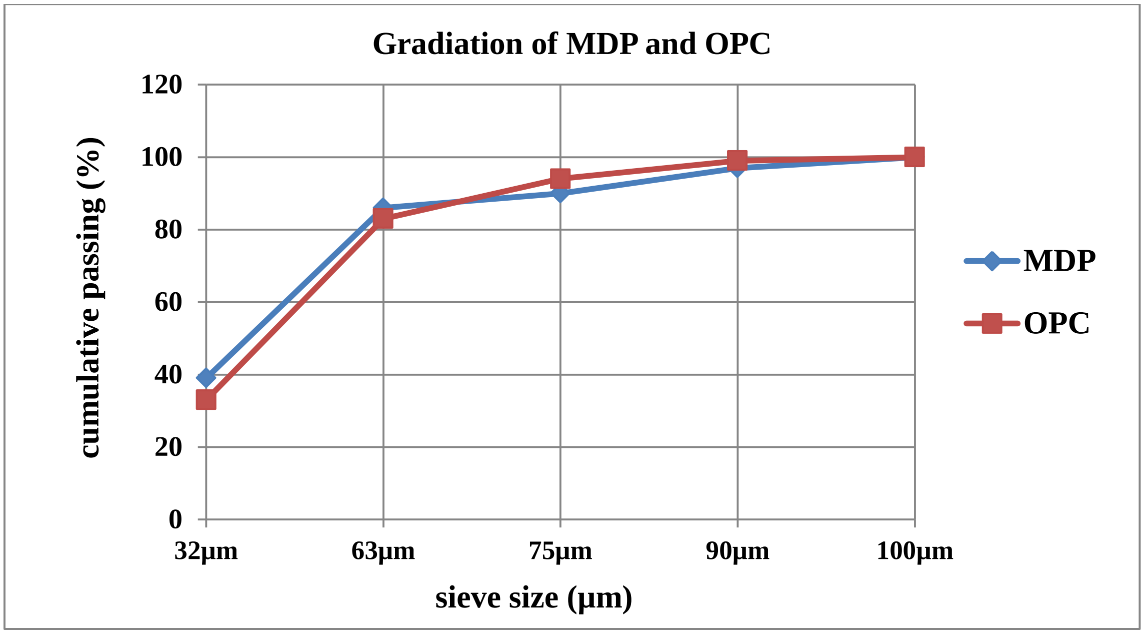

Figure 4.1 Gradation of marble dust powder (MDP) and OPC cement

This figure shows that the marble dust powder is finer than the cement for sieve size less than 68.14µm (where the two graphs meet) and the cement is finer for sieve sizes greater than this size, showing that the marble dust powder contains some particle coarser than cement but on average it is finer than Ordinary Portland cement. From the result of particle size analysis, the average size of the marble dust powder particles were found to be 39.26µm and 90% of the particles were of size less than 75µm, whereas cement has an average fineness of 42.54µm which is greater than the marble dust powder and 90% of the particles were less than 70.64µm which is less than the marble dust powder (**Appendix-G**).

4.2 Results and Discussions on Consistency of Blended Pastes

Normal consistency of pastes containing marble dust powders are shown in Table 4.2. The control paste or the paste without marble dust powder had normal consistency of 32%. All of the pastes containing marble dust powder showed normal consistency equal and higher than the control paste. For 4% replacement the normal consistency was similar with control paste. Starting from 8% replacement the normal consistency had shown a slight increment by 0.25% intervals and it increases continuously to 33% at 20% replacement.

Table 4.2 Normal consistency of blended pastes containing marble dust powder

S.No	Mix Code	Weight of OPC (gram)	Weight of MDP (gram)	Weight of water (milliliter)	Consistency (%) (ASTM C 187)
1	MDP0	400	0	128	32.00
2	MDP4	384	16	128	32.00
3	MDP8	368	32	129	32.25
4	MDP12	352	48	130	32.50
5	MDP16	336	64	131	32.75
6	MDP20	320	80	132	33.00

This finding on the consistency of the blended pastes conformed to the usual range of water to cement ratio for normal consistency which is between 26% and 33%. The increment on water requirement is due to the higher fineness of marble dust powder as compared to the fineness of cement.

4.3 Results and Discussions on Setting Time of Blended Pastes

The Ethiopian standard limits the initial setting time of Portland cement not to be less than 60 minutes and the final setting time not to exceed 10hrs. ASTM C 150 on the other hand, limits setting time of hydraulic cement to be between 45 to 375 minutes. The water added to cement is 85% of water that gives a paste of standard consistence.

Table 4.3 Setting time of pastes containing marble dust powder

S.No	Mix Code	Weight of OPC (gm)	Weight of MDP (gm)	Weight of water (ml)	Initial setting time (minutes)	Final setting time (minutes)
1	MDP 0	300	0	109	115	221
2	MDP 4	288	12	109	126	236
3	MDP 8	276	24	109	134	241
4	MDP 12	264	36	109	139	253
5	MDP 16	252	48	109	144	265
6	MDP 20	240	60	109	158	282

From the results of experimental investigation, both initial and final setting time of blended pastes shown the addition of marble dust powder retarded the setting of pastes. However, this retardation was within limits as specified by different standards. Comparing results of this finding with standards, blended cements by addition of marble dust powder satisfy the requirement of ASTM C 150 limits and Ethiopian standards ES C.D 5.202, section 4.2.4.

4.4 Results and Discussions on Workability of Fresh Concrete

The potential strength and durability of concrete of a given mix proportion is very dependent on the degree of its compaction. It is vital, therefore, that the consistency of the mix be such that the concrete can be transported, placed, and finished sufficiently early enough to attain the expected strength and durability.

In order to assess the workability of the fresh concrete the slump test was conducted and carried out according to ASTM C 143. For each mix in the experiment program, a sample of freshly mixed concrete is placed in three layers and compacted by tamping rod in a frustum of cone mold. As shown in figure 4.2, the slump value is equal to vertical distance between the original and displaced position of the center of the top surface of the concrete after raising a mold.

Figure 4.2 Slump test of concrete

The trial mix for the control concrete gave a slump of 27mm, which meet the targeted slump of mix design i.e. 10-30mm. Table 4.1 below shows the slump value for all marble dust powder blended concretes.

Table 4.4 Slump test results

S.No	**Mix Code**	Replaced OPC (%)	W/C	Observed Slump (mm)
1	MDP 0	0	0.50	27
2	MDP 4	4	0.50	27
3	MDP 8	8	0.50	26
4	MDP 12	12	0.50	25
5	MDP 16	16	0.50	25
6	MDP 20	20	0.50	24

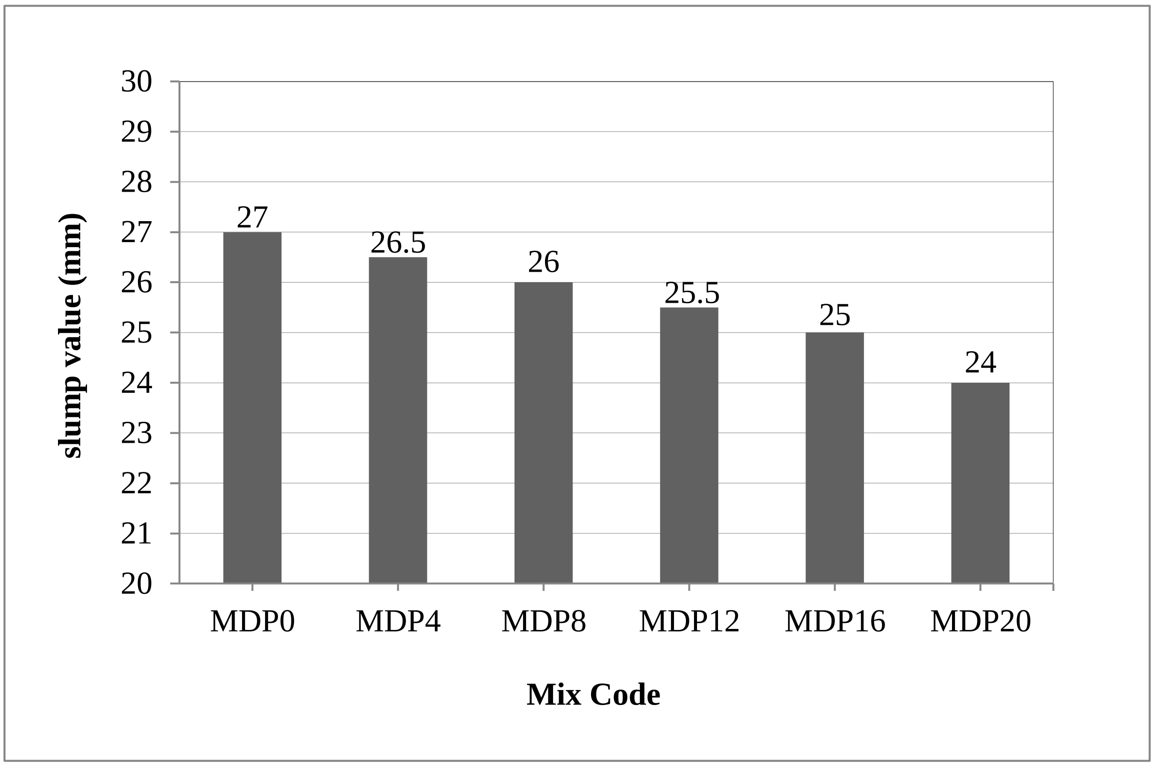

Figure 4.3 Graph for slump value

As can be seen from Table 4.4 and figure 4.3 above the slumps of the concrete containing marble dust powder have shown a slight reduction as the marble dust powder content increases. Table 4.2 (normal consistency table), shows that the normal consistency of the blended pastes increased with increase of the marble dust powder, this can also be an indication that in order to get a certain slump, OPC-MDP blended concretes needs a higher water content than a concrete with no marble dust powder. The probable reason for this may be the higher fineness of the marble dust powder which resulting in higher water demand. In order to get similar slump for the control and OPC-MDP concrete, the water content can be increased as the marble dust powder content increases.

4.5 Results and Discussions on Properties of Hardened Concrete

This part discusses the different properties of the hardened concrete which greatly affect the performance of concrete. In this research unit weight, compressive strength, flexural strength, tensile split strength and water permeability of the concretes are tested and presented in the sections below.

4.5.1 Results and Discussions on Unit Weight of Concrete

The weights and the dimension of the concrete cubes for this research are measured just before testing them for the compressive strength. These tests were conducted on a 28 days age of specimens prepared for compression test. The results for the weight and dimension are given in the **appendix**. In this section the unit weights of the concrete are calculated by using the 28 days weight and dimension and the results are as shown in Table 4.5 below.

Table 4.5 Unit weights of controlled and blended concretes

No	Mix Code	Replaced OPC (%)	Unit wt.(kg/m3)	Increase (%)
1	MDP 0	0	2388	0.00
2	MDP 4	4	2409	0.88
3	MDP 8	8	2434	1.93
4	MDP 12	12	2456	2.85
5	MDP 16	16	2476	3.69
6	MDP 20	20	2503	4.82

From the results, it was found out that a slight increment of unit weight up to 4.82% was observed when 20% of the cement was replaced by marble dust powder in sample MDP20. Whereas 0.88%, 1.93%, 2.85% and 3.69% increment were observed for 4%, 8%, 12% and 16% marble dust powder replacement in sample MDP4, MDP8, MDP12 and MDP16 respectively.

All the marble dust powder blended concretes in this research have higher density than the controlled concrete. Generally, the unit weight of concrete (density) increases as the amount of marble dust powder content increases which implies that marble dust powder used in this research has higher packing density than ordinary Portland cement.

4.5.2 Results and Discussions on Compressive Strength of Concrete

The compressive strength test of concrete is the most common test type for the hardened concrete. The reasons for these are; many codes and design manuals are based on this property, many other properties of concrete depend on the compressive strength and when compared to other tests this is an easy one. Figure 4.5 below shows a compressive strength test under progress.

Figure 4.4 Compressive strength of concrete being tested

The compressive strength of each of the concrete is determined by testing the cubes in a compression machine. For each of the mixes the average value of three samples is taken as their compressive strength. Table 4.6 shows average compressive strength values:

Table 4.6 Average compressive strength values of concrete samples

No	Mix Code	Replaced OPC (%)	Average compressive strength (N/mm^2)			
			7 days		28 days	
			Load (KN)	Strength	Load(KN)	Strength
1	MDP 0	0	599.50	26.65	835.88	37.15
2	MDP 4	4	613.13	27.25	854.73	37.59
3	MDP 8	8	622.73	27.68	857.70	38.12
4	MDP 12	12	596.55	26.51	830.10	36.89
5	MDP 16	16	578.70	25.72	821.03	36.49
6	MDP 20	20	565.13	25.12	809.30	35.97

As can be seen from Table 4.6 above, the compressive strength of the concrete with 4% and 8% marble dust powder have shown improvement over the control concrete by about 1.18% and 2.61% at 28 days respectively. On the other hand MDP12, MDP16 and MDP20 i.e. concretes with 12%, 16% and 20% marble dust powder, had shown a strength reduction by about 0.70%, 1.78% and 3.18% at 28 days. This shows that the compressive strength of the OPC-MDP blended concrete decreases beyond 8% marble dust powder increments. The probable reason for this is due to the high replacement of cement by marble dust powder, thus reducing cement content of the mixture which in turn causes a reduction in the hydration reaction. In addition to this the high content of marble dust powder resulted in a higher water requirement, making the water unavailable for the hydration of the cement. Table 4.7 below shows the strength activity index for all the concretes.

Table 4.7 Strength activity index of OPC-MDP concrete

No	Mix Code	At 7 days		At 28 days	
		Strength (Mpa)	Activity index	Strength (Mpa)	Activity index
1	MDP 0	26.65	100.00	37.15	100.00
2	MDP 4	27.25	102.25	37.59	101.18
3	MDP 8	27.68	103.86	38.12	103.20
4	MDP 12	26.51	99.47	36.89	99.30
5	MDP 16	25.72	96.50	36.49	98.22
6	MDP 20	25.12	94.26	35.97	96.82

The strength of the OPC-MDP concretes had shown an increase in activity index for the higher percentage marble dust powder replacement as the age of the specimen increased. For example the concrete MDP 20 i.e. the concrete with 20% marble dust powder, had a strength activity index of 94.26% at 7 days which increase to 96.82% at 28 days. This is one evidence which shows that there may be a reaction between the marble dust powder and the cement i.e. if the marble dust powder had been only a filler such strength activity improvement over time would not be noticed.

4.5.3 Results and Discussions on Flexural Strength of Concrete

Flexural strength of concrete is one way of estimating the tensile strength of concrete. During this test the specimen is subjected to a bending moment. For a bending force applied downward on a member supported simply at its two ends, fibers above the neutral axis are generally subjected to compressive stresses and those below the neutral axis to tensile stresses.

Figure 4.5 Beam specimens under flexural test

The flexural strength tests were conducted at twenty eight days. These results are summarized in table 4. 8. The calculation of the flexural stress is as follows:

$C = D/2$ cm…………………………………………………………………..……....…. [Eq.4.1]

$M = PL/3$ Nm……………….…………..………..…………………………..…..……..….... [Eq.4.2]

$I = bd^3/12$ m^4……………………………………..……………………..….....….…... [Eq.4.3]

$\sigma = Mc/I$ MPa……………………………………………………….…………........... [Eq.4.4]

Where: P = Failure Load σ = Bending strength

M = Maximum Moment L = span of specimen

I = Moment of Inertia D = depth of specimen

C = Centroidal depth W = width of specimen

Table 4.8 Average flexural strength value of the concretes

No	Mix Code	Replaced OPC (%)	Average flexural strength at 28 days		
			Load (kN)	Strength (Mpa)	(Gain/Loss)%
1	MDP 0	0	7.31	4.382	0.000
2	MDP 4	4	7.43	4.461	+1.803
3	MDP 8	8	7.55	4.527	+3.309
4	MDP 12	12	7.29	4.377	-0.114
5	MDP 16	16	7.21	4.327	-1.255
6	MDP 20	20	7.15	4.292	-2.054

At the twenty eight days age, the rate of flexural strength development of 0%, 4%, 8%, 12%, 16% and 20% of marble dust powder blended concretes were 4.382MPa, 4.461MPa, 4.527MPa, 4.377Mpa, 4.327 and 4.292MPa respectively. This indicates the rate of flexural strength development at 4% and 8% marble dust powder blended concretes were improved by 1.803% (0.079MPa) and 3.309% (0.145Mpa) from normal concrete respectively. Whereas, for 12%, 16% and 20% marble dust powder blended concretes the rate of flexural strength development were lowered by 0.114% (0.005Mpa), 1.255% (0.055MPa) and 2.054% (0.09MPa) from control concrete respectively.

Therefore, the experimental investigation on flexural strength shown that, the strength of the concrete has increased as the replacement percentage of the marble dust powder increased up to 8% by weight of cement. The flexural strength had shown a reduction pattern as the marble dust powder content of the concrete increases beyond 8%. The probable reason in the reduction of flexural strength is that the reduction of cement loses the binding property due to the addition of marble dust powder which implies marble dust powder acts partially as filler agent.

4.5.4 Results and Discussions on Tensile Split Strength of Concrete

The common method of estimating the tensile strength of concrete is through an indirect tension test. The splitting tensile test is carried out on a standard cylinder tested on its side in diametric compression. The horizontal stress to which the element is subjected is given by the following equation.

Horizontal tension $\sigma_t = 2P/\pi LD$ ...…………….…………….………..………...….… [Eq. 4.5]

Where: P = the applied compressive load

L = the cylinder length, and

D =the cylinder diameter

The test is carried out on cylindrical specimens using a bearing strip of 3mm plywood that is free of imperfections and is about 25mm wide. The specimen is aligned in the machine and the load is then applied (Mindess et.al, 2003). Figure 4.6 below shows the testing method for splitting tensile strength test.

Figure 4.6 Cylindrical specimens under tensile split test

Table 4.9 below shows the average tensile split strength test results at 28 days. The gain or lose strength with respect to the control mixes are also tabulated together.

Table 4.9 Average tensile split strength and relative strength of the concrete samples

S.No	Mix Code	Replaced OPC (%)	Average tensile split strength at 28 days		
			Load (kN)	Strength (N/mm^2)	(Gain/loss) %
1	MDP 0	0	104.80	3.336	0
2	MDP 4	4	104.83	3.341	+ 0.15
3	MDP 8	8	105.59	3.361	+ 0.75
4	MDP 12	12	104.90	3.339	+ 0.09
5	MDP 16	15	104.25	3.318	- 0.54
6	MDP 20	20	102.40	3.259	- 2.31

At the twenty eight days age, the splitting tensile strength gain of up to 0.15% (MDP 4), 0.75% (MDP 8) and 0.09% (MDP 12) were observed when 4%, 8%, and 12% of the cement was replaced by marble dust powder respectively. However, for marble dust powder blended concretes containing 16% and 20% marble dust powder by weight of cement were noticed, losses of 0.54% and 2.31% respectively as compared to the conventional concrete.

Therefore, the experimental investigation on splitting tensile strength shown that, the splitting tensile strength of concrete slightly increased with increasing marble dust powder content up to 8% replacement and starts to decrease for further increment of marble dust powder. Even though the difference is small, the concrete contain 4%, 8% and 12% marble dust powder shown improvement over the conventional concrete. However, there was a relatively a little bit variations observed in splitting tensile strength as compared to the results of compressive strength.

4.5.5 Results and Discussions on Water Permeability of Concrete

The non-steady state water permeability test was selected for this research. It was conducted on normal concrete cubes having a dimension of 150mm x 150mm x 150mm. The surfaces of the cubes were polished to remove any unwanted particle on the surfaces. The cubes where then placed in the permeability apparatus and the bolts were tightened to prevent any leakage of water. The specimens ready for test are as shown in Figure 4.7 below.

Figure 4.7 Concrete specimens adjusted for water permeability test

The pressure of the water is then adjusted to 3 bar (0.3MPa) for the first 24 hours, 5 bar (0.5MPa) for the next 24 hours and finally 7 bar (0.7MPa) for the last 24 hours i.e. total of 72 hours. At the end of the 72 hours period, all the valves supplying water and compressed air to the specimens were closed and the cubes were removed from the permeability rig and split. Figure 4.8, below shows a typical water penetrated sample just after splitting.

Figure 4.8 Typical cross section of concrete shows water penetration depth

Upon visual examination, the portion of the specimen into which water has penetrated appears darker than the rest, and immediately after splitting, this zone was marked and measurements were taken. To determine the average depth of penetration with more accuracy, measurements were taken at 15mm intervals. Table 4.10 lists the average and maximum depth of penetrations obtained for different samples (detailed results are given in the appendix).

Table 4.10 Average and maximum water penetration depth results of concrete samples

S.No	Mix Code	Replaced OPC (%)	Penetration depth (mm)	
			Average	Maximum
1	MDP 0	0	23.81	28.7
2	MDP 4	4	23.23	28.1
3	MDP 8	8	22.89	27.4
4	MDP 12	12	22.21	26.7
5	MDP 16	16	21.74	26.4
6	MDP 20	20	20.38	25.7

As observed from the Table 4.10 above, the average and maximum water penetration depths show some variation over the different types of concrete specimens with different percentage of marble dust powder. The average depth of water penetration varied from 20.38mm to 23.81mm for MDP20 and MDP0 respectively. The corresponding variation for the maximum depth of penetration was from 25.7mm to 28.7mm for MDP20 and MDP0 respectively. It can be said that the degree of variation from the most permeable concrete to the most impermeable concrete was about 16.83% and 11.67% depending on the average and maximum depth respectively. The concrete containing marble dust powder have shown improvement over the control concrete; and concretes with higher percentage of marble dust powder have shown less water penetration depth than concretes with lower percentage of marble dust powder which is due to the higher density of concretes containing marble dust powder implies is that MDP fills up all the gapes inside the concrete during hardening process.

CHAPTER FIVE

CONCLUSSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the experimental results, the marble dust powder used as cement part in concrete and their effects on different properties of cement as well as on performances of concrete are concluded as below.

- ✓ Higher replacements of cement by marble dust powder resulted in higher normal consistency and longer setting time.
- ✓ The workability of concrete containing marble dust powder decreases slightly as the marble dust powder content increases.
- ✓ The unit weight of the concretes containing marble dust powder has shown a slight increment as the marble dust powder content increases.
- ✓ High compressive strength of concrete was achieved when marble dust powder was replaced at 8% by weight of cement.
- ✓ At 28 days age test result, the flexural strength of the concrete has increased as the replacement percentage of the marble dust powder increased up to 8% and decreased for further replacement.
- ✓ From the results obtained for the split tensile strength of concrete, it is observed that the split tensile strength of concrete improved up to 12% replacement of cement by marble dust powder and decreased with further increase as compared to controlled concrete.
- ✓ The permeability test result clearly shown that water penetration depth decreases as the marble dust powder content of the concrete increases and all the concretes with marble dust powder have a penetration depth less than the conventional concrete.
- ✓ From present investigation on C-25 grade of concrete, it was found that the optimum percentage for replacement of marble dust powder with cement ranges from 4% to 12%.
- ✓ Finally, the results of this research work have shown that marble dust powder could effectively use in concrete up to 8% replacement of cement by weight and able to improve the properties of concrete over the conventional concrete.

5.2 Recommendations

Based on the insights gained from the study, the incorporation of marble dust powder in cement improves the performance of concrete. Issues which are not addressed in this research and areas for future works are also forwarded as recommendations as bellow.

1. Marble processing industries should have to use bag filter arrangements and vacuum pump technologies to collect marble dusts generated during cutting and polishing of the marble to clean the air before released to the atmosphere.
2. Marble dust powder as investigated in this research can be used as a cement replacing material with economical, technical and environmental advantages. Therefore concerned bodies like marble processing industries, cement industries and government entities should be made aware about this potential cement replacing material and promote its standardized production and usage.
3. The cement and marble processing industries in collaboration with higher education organizations in the country should work together and establish a research team to further study on the use of marble dust powder as cement replacing material.
4. This research mainly studied on the influence of marble dust powder on different properties of concrete. Some basic physical properties of this cement replacing material and its effect on cement properties have also been studied. However, further studies are required on the following items:
   i. The effects of different fineness of the marble dust powder on different properties of cement and concrete should also be studied.
   ii. Marble dust powder from different sources like Gelan marble factory, Saba dimensional stone, Tis Abay International, Berta Construction and other marble processing factories should also be studied.
   iii. The reaction between marble dust powders and ordinary Portland cement when mixed with water shall be checked using advanced technologies like X-ray diffraction analysis (XRD) and scanning electron microscopy (SEM).

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APPENDIXES

APPENDIX-A TRIAL CONSISTENCY TEST OF BLENDED PASTES

Trial No.	Wt. of blended powders [gm]	Wt. of water [ml]	W/C	Penetration depth [mm]
MDP 0				
1	400	126	0.3150	5
2	400	129	0.3225	14
3	400	128	0.3200	10
MDP 4				
1	400	127	0.3175	6
2	400	130	0.3250	15
3	400	128	0.3200	10
MDP 8				
1	400	128	0.3200	6
2	400	131	0.3275	15
3	400	129	0.3225	10
MDP 12				
1	400	129	0.3225	6
2	400	132	0.3300	14
3	400	130	0.3250	10
MDP 16				
1	400	130	0.3250	7
2	400	132	0.3300	13
3	400	131	0.3275	10
MDP 20				
1	400	130	0.3250	6
2	400	133	0.3325	12
3	400	132	0.3300	10

APPENDIX-B COMPRESSIVE STRENGTH OF OPC-MDP CONCRETES

B-1 Seven Days Compressive Strength of OPC- MDP Concretes

No	Age (days)	Dimension (mm)			Weight [Kg]	Failure Load [KN]	Compressive strength [MPa]
		L	W	H			
MDP 0 %							
1	**7**	150	150	150	8.065	617.40	27.44
2		150	150	150	7.675	581.40	25.84
3		150	150	150	8.105	599.85	26.66
Average					**7.948**	**599.50**	**26.65**
MDP 4 %							
1	**7**	150	150	150	7.964	587.70	26.12
2		150	150	150	8.063	641.25	28.50
3		150	150	150	8.055	610.43	27.13
Average					**8.027**	**613.13**	**27.25**
MDP 8 %							
1	**7**	150	150	150	8.192	616.05	27.38
2		150	150	150	8.085	628.43	27.93
3		150	150	150	8.124	623.70	27.72
Average					**8.134**	**622.73**	**27.68**
MDP 12 %							
1	**7**	150	150	150	8.240	599.85	26.66
2		150	150	150	8.165	598.50	26.60
3		150	150	150	8.188	591.30	26.28
Average					**8.198**	**596.55**	**26.51**
MDP 16 %							
1	**7**	150	150	150	8.369	561.83	24.97
2		150	150	150	8.374	581.85	25.86
3		150	150	150	8.298	592.43	26.33
Average					**8.347**	**578.70**	**25.72**
MDP 20 %							
1	**7**	150	150	150	8.551	591.53	26.29
2		150	150	150	8.406	540.90	24.04
3		150	150	150	8.356	562.95	25.02
Average					**8.438**	**565.13**	**25.12**

B-2 Twenty Eight Days Compressive strength of OPC- MDP concretes

No	Age (days)	Dimension (mm)			Weight [kg]	Failure Load [KN]	Compressive strength [MPa]
		L	W	H			
MDP 0 %							
1	**28**	150	150	150	8.097	843.75	37.50
2		150	150	150	8.042	823.95	36.62
3		150	150	150	8.037	839.93	37.33
Average					**8.059**	**835.88**	**37.15**
MDP 4 %							
1	**28**	150	150	150	8.143	831.60	36.96
2		150	150	150	8.163	855.23	38.01
3		150	150	150	8.083	850.28	37.79
Average					**8.130**	**854.73**	**37.59**
MDP 8 %							
1	**28**	150	150	150	8.255	867.90	38.57
2		150	150	150	8.285	860.02	38.22
3		150	150	150	8.105	845.17	37.56
Average					**8.215**	**857.70**	**38.12**
MDP 12 %							
1	**28**	150	150	150	8.249	841.28	37.39
2		150	150	150	8.249	821.93	36.53
3		150	150	150	8.369	827.10	36.76
Average					**8.289**	**830.10**	**36.89**
MDP 16 %							
1	**28**	150	150	150	8.387	816.98	36.31
2		150	150	150	8.407	836.10	37.16
3		150	150	150	8.277	810.00	36.00
Average					**8.357**	**821.03**	**36.49**
MDP 20 %							
1	**28**	150	150	150	8.453	812.70	36.12
2		150	150	150	8.458	797.63	35.45
3		150	150	150	8.433	817.65	36.34
Average					**8.448**	**809.33**	**35.97**

APPENDIX-C FLEXURAL STRENGTH OF OPC-MDP CONCRETES

C-1 Twenty Eight Days flexural strength of OPC- MDP concretes

No	Age (day)	Dimension (mm)			P [KN]	M [Nm]	I [m4]	C [cm]	σ [MPa]
		L	W	H					
MDP 0 %									
1	**28**	500	100	100	7.2795	727.95	8.33E-06	5.00	4.36370
2		500	100	100	7.3399	733.99	8.33E-06	5.00	4.40394
3		500	100	100	7.2918	729.18	8.33E-06	5.00	4.37508
Average					**7.3037**	**730.37**	**8.33E-06**	**5.00**	**4.38222**
MDP 4 %									
1	**28**	500	100	100	7.59.44	759.44	8.33E-06	5.00	4.55664
2		500	100	100	7.2517	725.17	8.33E-06	5.00	4.35102
3		500	100	100	7.4584	745.84	8.33E-06	5.00	4.47504
Average					**7.4348**	**743.48**	**8.33E-06**	**5.00**	**4.46088**
MDP 8 %									
1	**28**	500	100	100	7.4956	749.56	8.33E-06	5.00	4.49736
2		500	100	100	7.5573	755.73	8.33E-06	5.00	4.53438
3		500	100	100	7.5822	758.22	8.33E-06	5.00	4.54932
Average					**7.5450**	**754.50**	**8.33E-06**	**5.00**	**4.5270**
MDP 12 %									
1	**28**	500	100	100	7.1259	712.59	8.33E-06	5.00	4.27554
2		500	100	100	7.4019	740.19	8.33E-06	5.00	4.44114
3		500	100	100	7.3553	735.53	8.33E-06	5.00	4.41318
Average					**7.2944**	**729.44**	**8.33E-06**	**5.00**	**4.37664**
MDP 16 %									
1	**28**	500	100	100	7.1406	714.06	8.33E-06	5.00	4.28436
2		500	100	100	7.2546	725.46	8.33E-06	5.00	4.35276
3		500	100	100	7.2379	723.79	8.33E-06	5.00	4.34274
Average					**7.2110**	**721.10**	**8.33E-06**	**5.00**	**4.3266**
MDP 20 %									
1	**28**	500	100	100	7.1633	716.33	8.33E-06	5.00	4.29798
2		500	100	100	7.2493	724.93	8.33E-06	5.00	4.34958
3		500	100	100	7.0455	704.55	8.33E-06	5.00	4.22730
Average					**7.1527**	**715.27**	**8.33E-06**	**5.00**	**4.29162**

APPENDIX-D TENSILE SPLIT STRENGTH OF OPC-MDP CONCRETES

D-1 Twenty Eight Days Tensile Split strength of OPC- MDP concretes

No	Age (days)	Dimension (mm)		Weight [gm]	Failure Load [KN]	Tensile split strength [MPa]
		D	H			
MDP 0 %						
1	**28**	100	200	3.799	104.21	3.317
2		100	200	3.783	104.63	3.330
3		100	200	3.804	105.55	3.360
Average				**3.795**	**104.80**	**3.336**
MDP 4 %						
1	**28**	100	200	3.833	103.92	3.308
2		100	200	3.814	106.02	3.375
3		100	200	3.806	104.94	3.340
Average				**3.818**	**104.96**	**3.341**
MDP 8 %						
1	**28**	100	200	3.836	105.84	3.369
2		100	200	3.853	104.65	3.331
3		100	200	3.840	106.28	3.383
Average				**3.843**	**105.59**	**3.361**
MDP 12 %						
1	**28**	100	200	3.861	106.08	3.377
2		100	200	3.898	104.73	3.334
3		100	200	3.850	103.88	3.307
Average				**3.870**	**104.90**	**3.339**
MDP 16 %						
1	**28**	100	200	3.932	104.40	3.323
2		100	200	3.868	103.10	3.282
3		100	200	3.885	105.24	3.350
Average				**3.895**	**104.25**	**3.318**
MDP 20 %						
1	**28**	100	200	3.930	101.01	3.215
2		100	200	3.935	103.35	3.290
3		100	200	3.910	102.83	3.273
Average				**3.925**	**102.40**	**3.259**

APPENDIX-E WATER PENETRATION TEST MEASUREMENTS

Mix code	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	Avg. [mm]	Max [mm]
MDP0	19.3	20.1	23.2	25.4	27.5	28.7	26.5	24.5	23.2	19.7	23.81	28.7
MDP4	19.1	21.2	23.6	26.5	28.1	27.3	25.4	23.3	20.4	17.5	23.23	28.1
MDP8	18.8	20.4	22.4	24.7	25.7	26.3	27.4	23.5	21.3	18.4	22.89	27.4
MDP12	18.1	19.1	22.2	25.1	26.1	26.7	24.3	23.1	20.3	17.1	22.21	26.7
MDP16	18.2	19.3	22.1	24.4	26.4	24.6	23.5	21.6	19.4	17.9	21.74	26.4
MDP20	16.6	17.3	19.1	21.2	23.4	24.2	25.1	23.1	17.7	16.1	20.38	25.7

APPENDIX-F COMPLETED CONCRETE MIX DESIGN FORM

Stage	Item	Reference/Calculation	Value	
1	1.1 Characteristic strength (fc)	Specified	25 N/mm^2 @ 28days	
	1.2 Margin (M)	Specified	13 N/mm^2	
	1.3 Target mean strength (fm)	$f_m = f_c + M$	38 N/mm^2	
	1.4 Cement strength class	Specified	42.5R	
	1.5 Aggregate type: coarse	Crushed		
	1.6 Aggregate type: fine	Uncrushed		
	1.7 Free-water cement ratio	From figure & Table	0.57	min=0.50
	1.8 Maximum free-water/ cement ratio.	Specified	0.50	
2	2.1 Slump	Specified	10mm - 30mm,	
	2.2 Maximum aggregate size	Specified	20mm	
	2.3 Free-water content	Table 3 $2/3W_f+1/3W_c$	170kg/m^3	
3	3.1 Cement content	$\frac{\text{free water content}}{\text{free water/cement}}$	340 kg/m^3	
4	4.1 Relative density of aggregate (SSD)	Readings from figure	2.63	
	4.2 Concrete density		2400 kg/m^3	
	4.3 Total aggregate content	2400 – 340 – 170	1890 kg/m^3	
5	5.1 Grading of fine aggregate	% Passing 600µm	50 %	
	5.2 Proportion of fine aggregate	Readings from figure	33 %	
	5.3 Fine aggregate content	1890*0.33	624 kg/m^3	
	5.4 Coarse aggregate content	1890 – 624	1266 kg/m^3	

Stage	Quantities	Cement	FA	CA	Water
6	Per m^3	340 kg	624 kg	1266 kg	170 kg
	Trial Mix 0.28026m^3	96 kg	174 kg	354 kg	48 kg

APPENDIX-G AVERAGE PARTICLE SIZE OF OPC AND MDP BY LINEAR INTERPOLATION

Ordinary Portland Cement (OPC)

X	**Y**
63μm	83%
X	50%
32μm	33%

$$X = X_1 + \frac{Y - Y_1}{Y_2 - Y_1}(X_2 - X_1)$$

$$X = 32 + \frac{50 - 33}{83 - 33}(63 - 32)$$

$$\mathbf{X = 42.54\mu m}$$

Marble Dust Powder (MDP)

X	**Y**
63μm	86%
X	50%
32μm	39%

$$X = X_1 + \frac{Y - Y_1}{Y_2 - Y_1}(X_2 - X_1)$$

$$X = 32 + \frac{50 - 39}{86 - 39}(63 - 32)$$

$$\mathbf{X = 39.26\mu m}$$

75μm … … … 94%

X … … … … . 90%

63μm … … . 83%

$$X = 63 + \frac{90 - 83}{94 - 83}(75 - 63) = \mathbf{70.64\mu m}$$

Interpolation for particle sizes distribution at which MDP and OPC samples have the same value (where the two graphs have crossed each other).

75μm … … … 94%

X_1 … … … Y_1

63μm … … . 83%

$$X = 63 + \frac{y - 83}{94 - 83}(75 - 63)$$

$$X = 0.92y - 27.55$$

75μm … … … … 90%

X_2 … … … … … Y_2

63μm … … … .86%

$$X = 63 + \frac{y - 86}{90 - 86}(75 - 63)$$

$$X = 3y - 195$$

$X_1 = X_2$ and $y_1 = y_2$, since they have same coordinate.

Therefore, the value of $X = 68.14\mu m$

APPENDIX-H SAMPLE PHOTOS TAKEN DURING THE RESEARCH

Photo 1: Concrete making materials: marble dust powder (top left), cement (bottom left), sand (top right) and coarse aggregate (bottom right).

Photo 2: Prepared MDP & OPC at different (%) for blending (right) and slump test (left)

Photo 3: Sample quartering for coarse aggregate (using riffle box on the right).

Photo 4: Unit weight test using known volume (left) and sieving MDP using shaker (right)

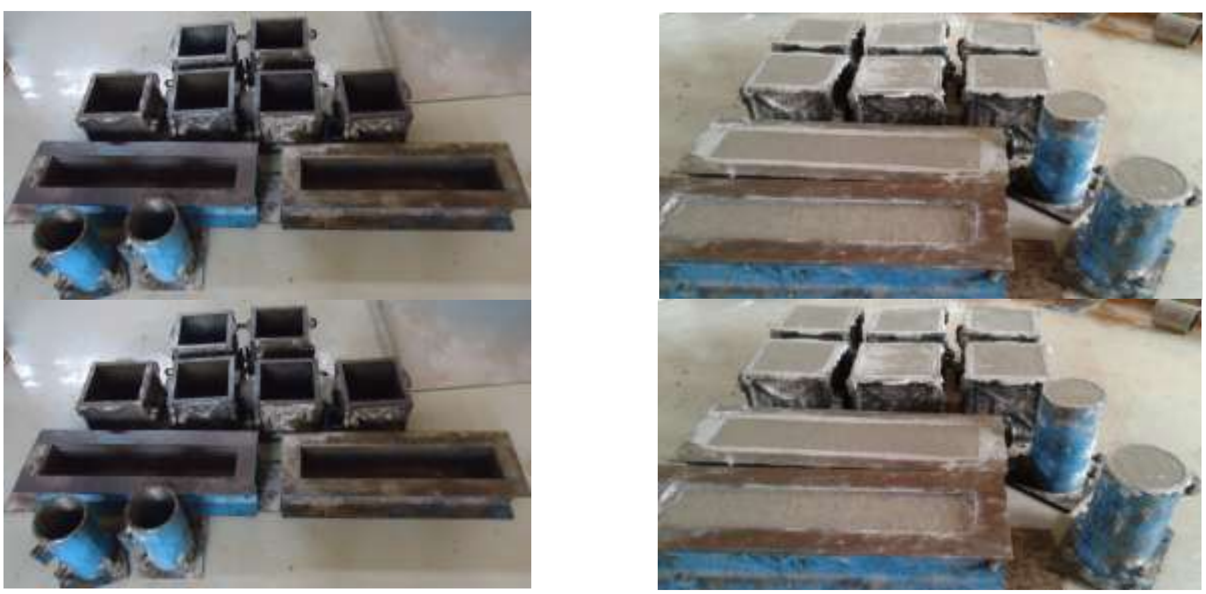

Photo 5: Oiled concrete molds (left) and casted concrete spacimens being trowled (right)

Photo 6: Concrete specimens in curing pond (left) and after curing (right)

Photo 7: Cubes under compression test on the left and after compression test on the right

Photo 8: Concrete beams under flexural test on the left and after flexural test on the right

Photo 9: Cylinders under tensile split test on the left and after tensile split test on the right

Photo 10: Permeability test: Cubes under the rig (top left), under splitter machine before split (bottom left), after split (top right) and cross sectional view after split (bottom right).

Photo 11: Specific gravity and water absorption test for aggregates by using pycnometer

Photo 12: Initial setting time (right) and final setting time (left) for blended pastes

Photo 13: Dry state mix of Coarse and Fine aggregates (on the left) and marble powder added to the dry mix (on the right).

Photo 14: Over all Concrete making materials ready for mix.