USING MARBLE WASTE POWDER IN CEMENT AND CONCRETE PRODUCTION

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By

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ABSTRACT

In this study, the possibility of using marble waste powder in cement and concrete production was examined by studying the effects of blending of marble waste powder with cement on the physical and chemical properties of cement paste and hardened mortar and by studying the effects of blending of marble waste powder with cement and sand on the performance of fresh and hardened concrete.

For studying the properties of marble waste powder blended cements, a total of nine marble waste powder blended cements, with two different blain fineness of marble waste powder, were prepared by blending the marble waste powder with cement in replacement ranges from 5% to 20% with 5% increment by weight of cement.

In studying the performance of concretes, a total of eighteen concrete mixes were prepared with cement and sand blended with marble waste powder in separate mixes with replacement ranges from 5% to 20% with 5% increment by weight of cement and sand respectively. For each replacement range, two classes of concrete, C-25 and C-50, mixes were prepared for both cement and sand replacement cases.

Different test results together with literature review were used to analyze the effects of using marble waste powder in cement and concrete production.

The investigation of this thesis, therefore, has revealed that compressive strengths of cement pastes from 5% marble waste powder blended Portland cement are comparable with that of cement pastes from 100% Ordinary Portland cement.

For 10 and 15% replacement ranges, though reduction in compressive strength is observed, blended cements at these percents satisfy the standard compressive strength limits for high early strength of class of 42.5 MPa as per the EN 197-1 standard.

Observation on the test results also indicate that the effects of blending marble waste on the properties of cement such as consistency, setting times, insoluble residue, and soundness remain within the acceptable ranges of different standards.

The investigation also indicates that replacement of cement by marble waste powder at 5% range, in concrete production, results in comparable compressive strength as of concrete specimens without marble waste powder with slight slump reduction for both C-25 and C-50 classes. Increment of replacement ranges beyond 5%, in concrete production, results in reduction of compressive strength and slump.

Replacement of sand by marble waste powder from 5-20% ranges, in concrete production, results in similar and mostly enhanced performance than the control concrete specimens; with similar compressive strength to the control specimens, with slump improvement and water permeability depth reduction than the control specimens in both C-25 and C-50 classes.

Key words: Marble waste powder, Blending, Performance of concrete

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ASTM	American Society for Testing Materials
BS	British Standard
$CaCO_3$	Calcium Carbonate
C_3S	Tricalcium Silicate
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_4AF	Tetra calcium Alumino Ferite
CO_2	Carbon Dioxide
$(CaOH)_2$	Calcium Hydroxide
CH	Calcium Hydroxide
CaO	Calcium Oxide
CSA	Canadian Cement Association
CSF	Condensed Silica Fume
CSH	Calcium Silicate Hydrate
cm^2/g	Centimeter square per gram
DOE	Department of Environmental of the British
DIS	Draft International Standard
E.C	Ethiopian Calendar
ES	Ethiopian Standard
EN	Euro Norm
Fig	Figure
Fe_2O_3	Iron Oxide
GGBS	Ground Granulated Blast-furnace Slag
gm	Gram

ICAR	International Center for Aggregates Research
in	Inch
I.R	Insoluble Residue
ISO	International Organization for Standardization
kg	Kilo gram
kg/cm^3	Kilogram per cubic centimeter
kJ/kg	Kilo Joule per kilogram
kN	Kilo Newton
LOI	Loss on Ignition
m	Meter
m^3	Meter cube
m/s	Meter per second
m^2	Meter square
m^2/kg	Meter square per Kilogram
MPa	Mega Pascal
MgO	Magnesiun Oxide
mm	Millimeter
N/mm^2	Newton per square millimeter
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
PC	Portland Cement
PFA	Pulverized Fuel Ash
PLC	Portland Limestone Cement
Psi	Pounds per square inch
RH	Relative Humidity
SCC	Self Compacting Concrete
SiO_2	Silicon Dioxide

SO_3	Sulphur Trioxide
U.S.	United States
s	Second
UK	United Kingdom
w/c	Water to cement ratio
w/cm	Water to cementitious material ratio
%	Percent
°C	Degree Centigrade
°F	Degree Faraniet
µm	Micrometer

CHAPTER ONE

INTRODUCTION

1.1. General

Nowadays, concrete made with Portland cement is probably the most widely used man made material in the world. Despite this fact, concrete production is one of the concerns worldwide that impact the environment with major impact being global warming due to CO_2 emission during production of cement. It is estimated that cement production is responsible for about 3% of the global anthrogenic greenhouse gas emission and for 5% of the global anthrogenic CO_2 emission [39].

As about 50% of the CO_2 released during cement production is related to the decomposition of limestone during burning, mixing of clinker with supplementary materials called blending is considered as a very effective way to reduce CO_2 emission [39].

Most common blending materials used in cement production added in plant or sites are industrial wastes. This is due to the fact that recycling of industrial wastes as blending materials has technical, economical and environmental benefits besides the reduction of CO_2 emission from cement production.

The technical importance of using wastes and by-products in concrete production is expressed by performance improvement of concrete. The economical benefit usually attributes to the reduction of the amount of expensive and or scarce ingredients with cheap materials. Environmentally, when industrial wastes are recycled not only the CO_2 emissions are reduced but residual products from other industries are reused and therefore less material is dumped as landfill and more natural resources are saved [5].

Fly ash, blast furnace slag and silica fume are most widely used industrial wastes in place of cement for concrete production attributed to their reactivity nature called pozzolanic behavior.

In addition to pozzolanas, other inert by-products and waste materials have been used in concrete and mortar production as inert filler for similar reasons. Among these, marble waste powder which is a by-product of marble processing factory was studied by many researchers for its use in concrete and mortar production as sand replacing or cement replacing material. Most of the researches showed positive results and benefits. However as the by-product i.e. the powder differs chemically depending on the parent marble rocks which depends on the locality, degree of metamorphism and other factors; and also as the physical characteristics of the by-product depends on the polishing work, it is necessary to conduct similar research in our country to incorporate it in concrete and cement production for reduction of environmental pollution and sustainable use of natural resources.

As marble is the derivative of limestone with similar constitution with that of limestone, and as in marble industry both limestone and marble which can take polish are considered as marble and worked together in the factory, in this literature review, formation and properties of both limestone and marble are presented. In addition, as calcium carbonate filler originated from marble or limestone is commonly named as limestone filler, previous studies of limestone filler in cement and concrete is presented for developing theories and concepts.

1.2. Production of Marble, as Dimensional Stone, in Ethiopia

The term "dimensional stone" is defined by United States Bureau of Mines as naturally occurring rock material cut, shaped or selected for use in blocks, slabs, sheets or other construction units of specified shapes or sizes and used for external or interior parts of buildings, foundations, curbing, paving, flogging, bridges, revetments or other architectural or engineering purposes. The term is also applied to quarry blocks from which pieces of fixed dimensions may be cut [6].

Marble, granite, limestone, and sandstone provide the bulk of dimensional stone; although slate, diorite, basalt and diabase are included. The classification of dimensional stone is not strictly adhered to sedimentary, igneous and metamorphic grouping of geology, as the stone trade name under "granite" refers to all true granite and gabbro, norite, and syenite. Likewise all crystalline limestone, travertine, sandstone and serpentine that are capable of taking a polish are grouped under marble in addition to the true marble [6].

The commercial definition of marble refers to all crystalline rocks predominantly composed of calcite, dolomite, or serpentine. The root word for marble-mar more- was used by the Italians in ancient Rome, referring to all hard rocks capable of taking a polish including granite. However, marble in the geologic usage is a metamorphosed limestone or dolostone, which obliterated its original texture due to intensive re-crystallization [6].

The marble deposits of Ethiopia have been known and exploited for many years. However, this segment of the stone industry did not start to develop more strongly until the early 1990"s.At present; there are several dimensional stone producing companies in Ethiopia. The largest is National Mining Company working several quarries of limestone (Harar), marble (Wellega) and granite (Harar and Wellega).A modern processing plant is located in Awash. The Ethiopian Marble Processing Industries produce marble from Gojam region and limestone from Harar. The company has three marble processing plants. Saba Stone Company, in the north, produces marble, granite and limestone from Tigray region [7].

Several companies are presently joining the industry including the Berta Company and Tis Abay International.

Table 1.1: Dimensional stone producing companies in Ethiopia

S.No	**Name of company**	**Estimated annual production (m^2)**	**Type of stone processed**
1	Ethiopian Marble Processing Enterprise	150,000.00	Marble and limestone
2	Saba Stone Company	180,000.00	Marble, limestone and granite
3	National Mining Corporation	250,000.00	Marble, limestone and granite
4	Berta Marble	25,000.00	Marble and limestone

1.3. Justification for the Thesis

There are two types of by-products of marble processing. During marble processing, 30% of the stone (in case of unprocessed stone) goes to scrap because of being smaller size and/or irregular shape. This is then sold to chip manufacturers. In case of semi-processed slab, the scrap level reduces to 2-5%. The other waste material is slurry. It is basically the water containing marble powder. The water is reused till it gets thick enough (70% water and 30% marble powder) to be reused. It can be safely estimated that 1 ton of marble stone processed in gang-saw or a vertical/horizontal cutter produces almost 1 ton of slurry (70% water) [8].

In Ethiopia 6662, 7200, 7900, 8100 and 8100 metric tons of marble commodities were produced in the year 2000,2001,2002,2003 and 2004 respectively [3] which implies that 30% of this mineral was lost as waste. Currently the amount of loss as waste is increasing as more other companies joined the industry than before.

In addition to loss, disposal of this waste material will cause the following environmental problems:

a) If the waste is disposed on soils, the porosity and permeability of topsoil will be reduced, the fine marble dust reduces the fertility of the soil by increasing its alkalinity [2].
b) When the waste is dumped and dried out, the fine marble dust suspends in the air and slowly spread out through wind to the nearby area [2].
c) When dumped along a catchment area of natural rainwater, it results in contamination of over ground water reservoir and also cause drainage problem [2].

Currently there are more than four marble processing plants in Ethiopia located in different towns. The Ethiopian Marble Processing Enterprise and Berta Marble are located in Adiss Ababa. The Ethiopian Marble Processing Enterprise has three branches located at Gulele, Nefasilk and Bole sub city.

The Gulele branch is located in a catchment of a river. It discharges the marble waste to the river. The Bole branch is also located in a catchment of a river and discharges the waste to the river. The Nifasilk branch deposits the waste inside its compound and used to sell this waste for outsiders as means of disposal in addition to income generation. Berta Marble is also located in a catchment of a river and discharges its by-product there.

On the other side, in Ethiopia the cost of cement and cement based construction materials are getting higher from time to time and there is 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 limited type of cement produced in the country .For instance Ordinary Portland cement and Portland Pozzolana cement types are the only product produced by cement factories and found on the market for all types of work which is expensive and uneconomical [9]. Trials to solve cement shortage only by increasing cement factories have another negative environmental impact due to the emission of CO_2 from the factories.

Therefore, this is to study the use of marble waste powder in construction industry to address environmental problem due to the waste and to seek alternative cement and sand based material and for efficient use of natural resources.

1.4. Objectives of the Thesis

The main objectives of this study are three.

1. To study the influence of percentage replacement of cement by marble waste powder on the physical and chemical properties of Portland cement paste and hardened mortar.
2. To study the effects of percentage replacement of cement by marble waste powder on different properties of concrete.
3. To study the effects of percentage replacement of sand by marble waste powder on different properties of concrete.

Furthermore, as part of the research objectives, the thesis will draw conclusions and forward recommendations based on the research finding and indicate areas for further study.

1.5. Scope of the Study

The research will cover studying physical and chemical properties of marble waste powder blended Portland cement and studying compressive strength, flexural strength and water permeability of concrete produced by marble waste powder blended cement, and marble waste blended sand.

Throughout the investigation, the research is limited to marble waste powder from the three factories of The Ethiopian Marble Processing Enterprise which process limestone and marble.

1.6. Methodology

In order to achieve the objectives of the research and for the development of concepts, which are fundamental for the formation of the whole research work, a comprehensive literature review is made to understand the previous efforts which include the review of text books, periodicals and academic journals, seminars and research papers.

The method followed to achieve the objectives of the research determines the required data, which intern is a ground to decide on type and method of data collection and their analysis. Different alternative data collection methods such as experiments, observations and archival records are examined and used when proved suitable.

Both primary data (collected personally) from the source itself and secondary data from different sources is collected and used for the analysis.

The test results were presented in tabular and graphical forms and the analysis and discussions were also made on the research findings both qualitatively and quantitatively. Finally based on the findings, conclusions and recommendations were forwarded.

1.7. Structure of the Research

The thesis has six chapters that discuss various aspects of cement and concrete related with relevance of the thesis. Chapter one explains the background and the objectives of the research. Chapter two is literature review which provides a general understanding of previous studies and theories related to the research .Chapter three discusses the properties of materials used in the investigation. Chapter four deals with the experimental program that was used in the research. Chapter five is about the analysis and discussion of the results obtained from the study. The last chapter draws conclusions from the research and provides recommendations. Other data are presented in the Appendices.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

During the past years, concrete and cement technology have attained a lot of achievements .One of the achievements is the incorporation of industrial wastes as filler or additive in cement and concrete production with technical, economical and environmental advantages.

Such waste materials was found to have either reactive or filler effect in cement and concrete production. Reactive materials are named pozzolanas and have been used widely worldwide where available. The use of inert fillers is also a common practice in European countries, especially in France [40].The addition of inactive materials or fillers, principally limestone, is increasingly accepted in European countries [41].

Since the European Standard for Common cement first published in 1992 as pre-standard ENV 197-1, there has been an increasing trend in the use of limestone as mineral additive in cement not only in the European countries but also in other parts of the world [41].Inert fillers have been also used as aggregate fillers in concrete production to improve particle packing density thereby properties of concrete. These days, the increasing trend towards the use of filler types and amount has led to worldwide research and development in the area.

2.2. Cement

Cement is a hydraulic binder and is defined as a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes which, after hardening, retains its strength and stability even under water[15].

The history of making cementing material is as old as the history of engineering construction. Some kind of cementing materials were used by Egyptians, Romans and Indians in their ancient constructions [10]. The early Greeks and Romans used cementing materials obtained by burning limestone. The remarkable hardness of the mortar used in early Roman brickworks, some of which still exist, presents sufficient evidence of the perfection which the art of cementing material had attained in ancient times [10].

The Greek and Romans had known the fact that certain volcanic ash and tuff, when mixed with lime and sand yielded mortar possessing superior strength and better durability in fresh or salt water. Roman builders used volcanic tuff found near Pozzuoli village near Mount Vesuvius in Italy. This volcanic tuff or ash mostly siliceous in nature thus acquired the name Pozzolana. Later on, the name Pozzolana was applied to any other material, natural or artificial, having nearly the same composition as that of volcanic tuff or ash found at Pozzuoli. The Romans, in the absence of natural volcanic ash, used powered tiles or pottery as pozzolana [10].

When we come to more recent times, the most important advance in the knowledge of cements, the forerunner to the discoveries and manufacture of all modern cements is undoubtedly the investigations carried out by John Smeaton. When he was called upon to rebuild the Eddy Stone Light House in 1756,he made extensive enquiries into the state of art existing in those days and also conducted experiments with a view to find out the best material to withstand the sever action of sea water. Finally, he concluded that limestone which contained considerable proportion of clayey material yielded better lime possessing superior hydraulic properties. In spite of the success of Smeaton"s experiments, the use of hydraulic lime made little progress, and the old practice of mixture of lime and pozzolana remained popular for a long period. In 1976 hydraulic cement was made by calcining nodules of argillaceous limestone. In about 1800 the product thus obtained was called Roman cement. This type of cement was in use till about 1850 after which this was outdated by Portland cement [10].

2.2.1. Portland Cement

Portland cement was developed from natural cements made in Britain in the early part of the nineteenth century, and its name is derived from its similarity to Portland stone, a type of building stone that was quarried on the Isle of Portland in Dorset, England [11].

It is the chief ingredient in cement paste and the binding agent in Portland cement concrete. It is a hydraulic cement that, when combined with water, hardens into a solid mass. Interspersed in an aggregate matrix it forms Portland cement concrete. 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 [37]. The Portland Cement Association 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 [37].

As the use of Portland cement was increased for making concrete, engineers called for consistently higher standard material for use in major works. Association of Engineers, Consumers and Cement manufacturers has been established to specify standards of cement. The German standard specification for Portland cement was drawn in 1877.The British standard specification was first drawn up in 1904.The ASTM specification was issued in 1904 [10].

2.2.1.1. Manufacturing Process of Portland Cement

Portland cement is produced by grinding cement clinker in association with gypsum to specified fineness depending on the requirements of the cement consumers. Cement clinker is produced on large scale by heating finely ground raw materials (Calcareous and Argillaceous materials) at very high temperature up to 1450 ^{o}C in rotary kilns [37].

Raw mixture preparation and raw mix blending, formation and grinding of clinker are the fundamental stages in the production of Portland cement [11].

2.2.1.1.1. Raw mix preparation and blending

The raw materials for Portland cement production are a mixture (as fine powder in the 'dry process' or in the form of a slurry in the 'wet process') of minerals containing calcium oxide, silicon oxide, aluminum oxide, ferric oxide and magnesium oxide. The raw materials are usually quarried from local rock, which in some places has already practically the desired composition and in other places requires the addition of clay and limestone, as well as iron ore, bauxite or recycled materials. The individual raw materials are first crushed, typically to below 50 mm. In many plants, some or all of the raw materials are then roughly blended in a "pre-homogenization pile". The raw materials are next ground together in a raw mill. Silos of individual raw materials are arranged over the feed conveyor belt. Accurately controlled proportions of each material are delivered onto the belt by weigh feeders. Passing into the raw mill, the mixture is ground to raw mix. The fineness of raw mix is specified in terms of the size of the largest particles, and is usually controlled so that there are less than 5%-15% by mass of particles exceeding 90 μm in diameter. It is important that the raw mix contains no large particles in order to complete the chemical reactions in the kiln, and to ensure the mix is chemically homogenous. In the case of a dry process, the raw mill also dries the raw materials, usually by passing hot exhaust gases from the kiln through the mill, so that the raw mix emerges as a fine powder. This is conveyed to the blending system by conveyor belt or by a powder pump. In the case of wet process, water is added to the raw mill feed, and the mill product is slurry with moisture content of 25-45% by mass. This slurry is conveyed to the blending system by conventional liquid pumps [11].

The raw mix is formulated to a very tight chemical specification. Typically, the content of individual components in the raw mix must be controlled within 0.1% or better. Calcium and silicon are present in order to form the strength producing calcium silicates. Aluminum and iron are used in order to produce liquid ("flux") in the kiln burning zone. The liquid acts as a solvent for the silicate forming reactions, and allows these to occur at an economically low temperature. Insufficient aluminum and iron lead to difficult burning of the clinker, while excessive amounts lead to low strength due to dilution of the silicates by aluminates and ferrites. Very small changes in calcium content lead to large changes in the ratio of alite to belite in the clinker, and to corresponding changes in the cement's strength growth characteristics. The relative amounts of each oxide are therefore kept constant in order to maintain steady conditions in the kiln, and to maintain constant product properties. In practice, the raw mix is controlled by frequent chemical analysis (hourly by X-Ray fluorescence analysis, or every three minutes by prompt gamma neutron activation analysis). The analysis data is used to make automatic adjustments to raw material feed rates. Remaining chemical variation is minimized by passing the raw mix through a blending system that homogenizes up to a day's supply of raw mix [11].

2.2.1.1.2. Formation and grinding of clinker

The raw mixture is heated in a cement kiln, with temperatures increasing over the length of the cylinder up to a peak temperature of 1400-1450 °C. A complex succession of chemical reactions take place as the temperature rises. The peak temperature is regulated so that the product contains sintered but not fused lumps. Sintering consists of the melting of 25-30% of the mass of the material. The resulting liquid draws the remaining solid particles together by surface tension, and acts as a solvent for the final chemical reaction in which alite is formed. Too low a temperature causes insufficient sintering and incomplete reaction, but too high a temperature results in a molten mass or glass, destruction of the kiln lining, and waste of fuel. When all goes to plan, the resulting material is clinker. On cooling, it is conveyed to storage. Some effort is usually made to blend the clinker, because although the chemistry of the raw mix may have been tightly controlled, the kiln process potentially introduces new sources of chemical variability. The clinker can be stored for a number of years before use. Prolonged exposure to water decreases the reactivity of cement produced from weathered clinker [11].

In order to achieve the desired setting qualities in the finished product, a quantity (2-8%, but typically 5%) of calcium sulfate (usually gypsum or anhydrite) is added to the clinker and the mixture is finely ground to form the finished cement powder. This is achieved in a cement mill. The grinding process is controlled to obtain a powder with a broad particle size range, in which typically 15% by mass consists of particles below 5 μm diameter, and 5% of particles above 45 μm. The measure of fineness usually used is the "specific surface", which is the total particle surface area of a unit mass of cement. The rate of initial reaction (up to 24 hours) of the cement on addition of water is directly proportional to the specific surface. Typical values are 320–380 m^2/kg for general purpose cements, and 450–650 m^2/kg for "rapid hardening" cements [11].

2.2.1.2. Environmental Concerns in Cement Production

Many of the aspects of cement making process are potentially environmentally damaging, although these risks can be minimized [12]. Cement manufacturing is an energy intensive process [12]. The enthalpy of formation of clinker from calcium carbonate and clay minerals is about 1500 to 1700 kJ/kg. However, because of heat loss during production, actual values can be much higher. The high energy requirements and the release of significant amounts of carbon dioxide make cement production a concern for global warming [11].

Carbon dioxide is produced during the calcination phase of the manufacturing process and also as a result of burning fossil fuels. Opportunity to reduce emissions through increased energy efficiency is only possible on the latter of the CO_2 emissions [12].Approximately 1 ton CO_2 is generated for making 1 ton of clinker [11].

2.2.1.3. Types and Standards of Cement

There are different standards for classification of Portland cement. The two major standards are the ASTM C150 standard, used primarily in the U.S., and European EN-197 standard [11].

2.2.1.3.1. American standard

Eight types of cement are covered in ASTM C 150 standard. These types and brief descriptions of their uses are listed in Table 2.1 below [37].

Table 2.1: Portland cement types and their uses as ASTM C 150 [37]

Cement type	Use
I	General purpose cement, when there are no extenuating conditions
II	Aids in providing moderate resistance to sulfate attack
III	When high-early strength is required
IV	When a low heat of hydration is desired
V	When high sulfate resistance is required
IA	A type I cement containing an integral air-entraining agent
IIA	A type II cement containing an integral air-entraining agent
IIIA	A type III cement containing an integral air-entraining agent

2.2.1.3.2. European standard

EN 197-1 defines 5 classes of common cement that comprise Portland cement as a main constituent. These classes differ from the ASTM classes [11].

I. Portland cement: comprising Portland cement and up to 5% of minor additional constituents

II. Portland composite cement: Portland cement and up to 35% of other single constituents

III. Blast furnace cement: Portland cement and higher percentages of blast furnace slag

IV. Pozzolanic cement: Portland cement and up to 55% of pozzolanic constituents

V. Composite cement: Portland cement, blast furnace slag and pozzolana or fly ash

Constituents that are permitted in Portland composite cements are blast furnace slag, silica fume, natural and industrial pozzolans, siliceous and calcareous fly ash, burnt shale and limestone [11].

2.2.1.4. Properties of Portland Cement

2.2.1.4.1. Chemical properties

It is a Portland cement's chemical properties that determine most of 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 [15].

2.2.1.4.1.1. Chemical composition

The composition of Portland cement distinguishes one type of cement from another. The phase compositions 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 "alite" (C_3S), "belite" (C_2S), and various forms of aluminates. The behavior of each type of cement depends on the content of these components [13].

Table 2.2: Main constituents in a typical Portland cement [11]

Chemical Name	Chemical Formula	Shorthand Notation	Percent by Weight
Tricalcium Silicate	$3CaOSiO_2$	C_3S	50
Dicalcium Silicate	$2CaOSiO_2$	C_2S	25
Tricalcium Aluminate	$3CaOAl_2O_3$	C_3A	12
Tetracalcium Aluminoferrite	$4CaOAl_2O_3Fe_2O_3$	C_4AF	8
Gypsum	$CaSO_4H_2O$	CSH_2	3.5

Tricalcium silicate (C_3S) hydrates and hardens rapidly and is largely responsible for initial set and early strength. Portland cements with higher percentages of C_3S will exhibit higher early strength [11].

Dicalcium silicate (C_2S) hydrates and hardens slowly and is largely responsible for strength increases beyond one week [11].

Tricalcium aluminate (C_3A) hydrates and hardens the quickest. It liberates a large amount of heat almost immediately and contributes somewhat to early strength. Gypsum is added to Portland cement to retard C_3A hydration. Without gypsum, C_3A hydration would cause Portland cement to set almost immediately after adding water [11].

Tetracalcium aluminoferrite (C_4AF) hydrates rapidly but contributes very little to strength. Its presence allows lower kiln temperatures in Portland cement manufacturing. Most Portland cement color effects are due to C_4AF [11].

2.2.1.4.1.2. Loss on ignition

Loss on ignition is calculated by heating up a cement sample to 900 – 1000 ^oC (1650 - 1830°F) until a constant weight is obtained. The weight loss of the sample due to heating is then determined. A high loss on ignition can indicate pre-hydration and carbonation, which may be caused by improper and prolonged storage or adulteration during transport or transfer [15].

Maximum loss on ignition permitted by BS 12:1991 and ASTM C150-94 is 3% and 4% respectively. But with cement containing a calcareous filler, 5% of the mass of the cement nucleus is allowed by EN 197-1992[29].The standard loss on ignition test is contained in EN 196-2 No.7:1994 Standard Test Methods for Determination of Loss on Ignition [29] in European standard and AASHTO T 105 and ASTM C 114: Chemical Analysis of Hydraulic Cement [11] in American standard

According to the Ethiopian standard the loss in mass on ignition shall not exceed 4% for Portland cement [14].

2.2.1.4.1.3. Insoluble residue

Insoluble residue which is determined by treating cement with hydrochloric acid is a measure of adulteration of cement, largely arising from impurities in gypsum. BS 12 1991 limits the insoluble residue to 1.5% content of a filler, the standard insoluble residue test is contained in EN 196-2 no,9;1994 standard test methods for determination of insoluble residue and EN 196-2 no 10 1994 standard test methods for determination of insoluble residue [9].

2.2.1.4.2. Physical properties

Portland cements are commonly characterized by their physical properties for quality controlling purposes. Their physical properties can be used to classify and compare Portland cements [11].

EN and ASTM standards have specified certain physical requirements for each type of cement [15].These properties include:

2.2.1.4.2.1. Fineness

Fineness is defined depending upon the method of measurement. It may be defined as sieve diameter, the width of the minimum square aperture through which particle pass, or surface diameter, diameter of sphere having the same surface as the surface of particle [15]. It is a general practice to describe the fineness of cement by a single parameter, the specific surface area [14].Fineness of Portland cement has great effects on hydration rate and thus the setting time, and the rate of strength gain. As an example, the smaller is the particle size, the greater the surface area-to-volume ratio. This causes more area available for water-cement interaction. The finer particles mainly affect the early strength of the cement (2 days) while the larger particles dominate the strength after this time. The effects of greater fineness on strength are generally seen during the first seven or twenty eight days [15].

There are, however, several disadvantages associated with high fineness. In fine cement, more gypsum is required for proper retardation because increased fineness makes more tricalcium aluminate available for early hydration. Grinding clinker to a high fineness requires more energy, increasing the production cost, and a higher early rate of hydration causes a higher early rate of heat liberation. If not properly dissipated, this heat may cause cracking especially in mass concrete construction. The reaction of fine cement with alkali-reactive aggregate is stronger [15].

Fineness, which has considerable effects on cement strength and hydration rate, is accepted as a vital parameter by European and American Standards [15].

The Wagner Turbid meter and the Blaine air permeability test for measuring cement fineness is required by the American Society for Testing Materials (ASTM).Another test to determine the fineness is Sieve Analysis. The fineness of cement is measured by sieving it on standard sieves [15].

According to European standard there are two methods to measure cement fineness as designated on EN 196-6,no.3,1989: Standard Test Method for Fineness of Portland Cement by the sieving method and EN 196-6,No.4,1989: Standard Test Method for Fineness of Portland Cement by air permeability method or blain method [9].

Blaine fineness of modern cement ranges from 3,000 to 5,000 cm^2/g (300 to 500 m^2/kg) [13]. According to the Ethiopian standard, Ordinary Portland Cement shall have a specific surface area of not less than 2250 cm^2/g [14].

2.2.1.4.2.2. Consistency of cement paste

For determination of the initial and final setting times and for the Le-Chatelier soundness test, neat cement paste of standard consistency has to be used. It is, therefore, necessary to determine for any given cement the water content of the paste which will produce the desired consistency. Consistency is measured by Vicat apparatus; the content of a standard paste is expressed as a percentage by mass of the dry cement. The European standard for consistency test is indicated on EN 196-3, No.5, 1994 [9].The usual range of water-cement ratio for normal consistency is between 26% and 33% [14].

2.2.1.4.2.3. Soundness

When referring to Portland cement, "soundness" refers to the ability of a hardened cement paste to retain its volume after setting without delayed destructive expansion. This destructive expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO). Most Portland cement specifications limit magnesia content and expansion. The typical expansion test places a small sample of cement paste into an autoclave (a high pressure steam vessel). The autoclave is slowly brought to 2.03 MPa (295 psi) and then kept at that pressure for 3 hours. The autoclave is then slowly brought back to room temperature and atmospheric pressure. The change in specimen length due to its time in the autoclave is measured and reported as a percentage. ASTM C 150, Standard Specification for Portland cement specifies a maximum autoclave expansion of 0.80 percent for all Portland cement types [15].

The standard autoclave expansion tests are:

AASHTO T 107 and ASTM C 151: Autoclave Expansion of Portland cement [11] in American standard and EN 196-3, No.7 1994: Standard Test Method for Soundness Test of Portland Cement [9] in European standard.

According to the Ethiopian standard, the expansion of Portland cement shall not exceed 10mm.If this is not satisfied, an additional test shall be made using aerated portion of the same sample. The maximum expansion of such aerated sub sample shall not exceed 5mm [14].

2.2.1.4.2.4. Setting time

The stiffening of a cement paste is called setting. The time starting from the mixing of cement and water until the cement paste sets is called the setting time [9].Cement paste setting time is affected by a number of items including: cement fineness, water-cement ratio, chemical content (especially gypsum content) and admixtures. Setting tests are used to characterize how a particular cement paste sets. For construction purposes, the initial set must not be too soon and the final set must not be too late. Additionally, setting times can give some indication of whether or not a cement is undergoing normal hydration [11].Normally, two setting times are defined:

Initial set occurs when the paste begins to stiffen considerably; final set occurs when the cement has hardened to the point at which it can sustain some load.

These particular times are just arbitrary points used to characterize cement; they do not have any fundamental chemical significance. Both common setting time tests, the Vicat needle and the Gillmore needle, define initial set and final set based on the time at which a needle of particular size and weight either penetrates a cement paste sample to a given depth or fails to penetrate a cement paste sample. The Vicat needle test is more common and tends to give shorter times than the Gillmore needle test. Table 2.2 shows ASTM C 150 specified setting times [11].

Table 2.3: ASTM C 150 specified setting times by test method [11]

Test method	Setting type	Time specification (minutes)
Vicat	Initial	45
	Final	375
Gillmore	Initial	60
	Final	600

The standard setting time tests are:

AASHTO T 131 and ASTM C 191: Time of Setting of Hydraulic Cement by Vicat Needle, AASHTO T 154: Time of Setting of Hydraulic Cement by Gillmore Needles, ASTM C 266: Time of Setting of Hydraulic-Cement Paste by Gillmore Needles [11] in American standard and EN 196-3.No.6.2, 1994: Standard Test Method for Determination of Initial Setting Time of Cement by Vicat Needle and EN 196-3, No 6.3, 1994: Standard Test Method for Determination of Final Setting Time of Cement by Vicat Neddle [9] in European standard.

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 [14].

2.2.1.4.2.5. Strength

Cement paste strength is typically defined in three ways: compressive, tensile and flexural. These strengths can be affected by a number of items including: water-cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate, manner of mixing and molding specimens, curing conditions, size and shape of specimen, moisture content at time of test, loading conditions and age [15]. Since cement gains strength over time, the time at which strength test is to be conducted must be specified. Typically times are 1 day (for high early strength cement), 3 days, 7 days, 28 days and 90 days (for low heat of hydration cement) [11].

2.2.1.4.2.5.1. Compressive strength

The most common strength test, compressive strength, is carried out on a 50 mm (2-inch) cement mortar test specimen [11] in American standard. The test specimen is subjected to a compressive load (usually from a hydraulic machine) until failure. Table 2.3 shows ASTM C 150 compressive strength specifications [11].

Table 2.4: ASTM C 150 Portland cement mortar compressive strength specification (MPa) [11]

Curing Time (days)	Portland cement type							
	I	IA	II	IIA	III	IIIA	IV	V
1					12.4	10.0		
3	12.4	10.0	10.3	8.3	24.1	19.3		8.3
7	19.3	15.5	17.2	13.8			6.9	15.2
28							17.2	20.7

Note: type II and IIA requirements can be lowered if either an optional heat of hydration or chemical limit on the sum of C_3S and C_3A is specified

According to European standard, the test is carried out on prismatic test specimen which is 40mmx40mmx160mm cement mortar that is subjected to a compressive load until failure.

The standard cement mortar compressive strength test is described in EN 196-1, No 4.8,1994: Standard Test Method for Compressive Strength of Cement Mortars [9] in European standard and AASHTO T 106 and ASTM C 109: Compressive Strength of Hydraulic Cement Mortars (Using 50-mm or 2-in Cube Specimens) [11] and ASTM C 349: Compressive Strength of Hydraulic Cement Mortars (Using Portions of Prisms Broken in Flexure) [11] in American standard.

2.2.1.4.2.5.2. Tensile strength

Although still specified by ASTM, the direct tension test does not provide any useful insight into the concrete-making properties of cements. It persists as a specified test because in the early years of cement manufacturing, it was the most common test since it was difficult to find machines that could compress a cement sample to failure [11].

2.2.1.4.2.5.3. Flexural strength

Flexural strength (actually a measure of tensile strength in bending) is carried out on cement mortar beam that is loaded at its center point until failure [11].

The standard cement mortar flexural strength test is described in: ASTM C 348: Flexural Strength of Hydraulic Cement Mortars [11] in American standard and EN 196-1, No4.7: Standard Test Method for Flexural Strength of Cement Mortars [9] in European standard.

2.2.1.4.2.6. Heat of hydration

The heat of hydration is the heat generated when water and Portland cement react. Hydration begins at the surface of the cement particles. Therefore, the total surface area of cement represents the material available for hydration. That is, the early rate of hydration depends on the fineness of the cement particles. However, at later stages, the effect of surface area diminishes and, consequently, fineness exercise no influence on the total heat of hydration. Heat of hydration is also influenced by the proportion of C_3S and C_3A in the cement, water-cement ratio, fineness and curing temperature. As each one of these factors is increased, heat of hydration increases. In large mass concrete structures such as gravity dams, hydration heat is produced significantly faster than it can be dissipated (especially in the centre of large concrete masses), which can create high temperatures in the centre of these large concrete masses that, in turn, may cause undesirable stresses as the concrete cools to ambient temperature. Conversely, the heat of hydration can help maintain favorable curing temperatures during winter [15].

2.3. Concrete

Concrete is a composite material which is made up of a filler and a binder. The binder (cement paste) glues the filler together to form a synthetic conglomerate. The constituents used for the binder are cement and water, while the filler can be fine or coarse aggregate [16].

The properties of concrete, workability, strength and durability, make it to be the most versatile and widely used manmade construction materials. The users of concrete usually need it to have such important properties in economical way.

The incorporation of different materials, like industrial wastes, in concrete production has been found to play role in achieving the required properties of concrete.

2.3.1. Workability of Concrete

ASTM C 125 defines workability 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 early age operations of placing, compacting and finishing [33].

A workable concrete allows full compaction using a reasonable amount of work. This helps in achieving maximum possible density (i.e. minimum possible voids) of concrete, which results in more strength and durability of concrete [33].

Three factors in concrete are involved in determining the consistency of concrete: water cement ratio, aggregate cement ratio and water content. Only two of the three factors are independent. If the aggregate cement ratio is reduced, the water content must increase for the w/c ratio to remain constant. The water required to maintain a constant consistency will increase as the w/c ratio is increased or decreased. The increase in fine aggregate to coarse aggregate ratio generally increases the water content required to produce a given workability. If finer aggregate is substituted in a mixture, the water content typically must be increased to maintain the same workability [32].Lowering the cement content of concrete with a given water content typically will lower workability. An increase in cement fineness decreases workability and produces excessive bleeding; a high fineness will cause a concrete mixture to lose workability more rapidly because of its rapid hydration.

Cement replacing materials also affect workability. For example freshly mixed concrete are generally more workable when a portion of the cementious material is fly ash, in part because of the spherical shape of fly ash particles; but highly reactive or pozzolanas can cause loss of workability through early hydration[32].

2.3.2. Strength of Concrete

Generally a concrete is required to provide a specified strength. The most common measure of concrete strength is the compressive strength, determined in either a cube test or a cylinder test [34].

The strength of concrete is very much dependent upon the hydration reaction .Water plays a critical role, particularly the amount used.The strength of concrete increases when less water is used to make concrete. The hydration reaction itself consumes a specific amount of water. Concrete is actually mixed with more water than is needed for the hydration reactions. This extra water is added to give concrete sufficient workability. The water not consumed in the hydration reaction will remain in the microstructure pore space. These pores make the concrete weaker due to the lack of strength-forming calcium silicate hydrate bonds. Some pores will remain no matter how well the concrete has been compacted [16].

Cement replacing materials can play roles in improving concrete strength by improving microstructure space of concrete.

2.3.3. Durability of Concrete

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 [38].

The 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 [38].

The durability of concrete is a function of permeability [40].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 thereby ensuring permeability [38].Cement replacing materials can play role in reducing the extent of voids in concrete which in turn improves permeability of concrete.

2.3.3.1. Permeability

Permeability is the movement of fluids across a porous medium as a result of pressure gradient. Thus concrete permeability refers to its ability to transmit fluids through it caused by pressure head; it applies to the transport of both gases and liquids [35].

Many test methods have been developed to measure the resistance of concrete to the movement or penetration of fluids (such as water, oxygen or carbon dioxide) or aggressive species (such as chlorides or sulfates). Some of these tests involve the measure of fluid flow in response to a hydraulic pressure gradient or moisture gradient, or they involve the measure of ionic movement in response to a concentration gradient, whereas other tests measure another property, such as electrical conductivity or resistivity, and relate this parameter to penetration resistance. Regardless of the test method applied, it is generally considered that the durability of concrete will be improved with its ability to resist the movement of fluids and ionic species [31].

2.3.3.1.1. Water permeability

The impermeability of concrete can be determined in the laboratory by applying water under controlled pressure to the surface of concrete and measuring the penetration of water in to the specimen [41] called water permeability test. As water represents the most important liquid among those penetrating through concrete [35], improvement in impermeability of concrete to water implies improvement in durability of concrete. Water permeability of concrete can be evaluated under both steady state and non steady state condition [35].

2.3.3.1.1.1. Steady state water permeability

In this case, water is allowed to move across the specimen until steady state flow is attained. This is done by subjecting the specimen to specific pressure and recording penetrated water until constant flow of water is obtained. The coefficient of permeability is then calculated by using Darcy"s law as show in equation 2.1 below.

$$K_w = Q/t\ .l/A.\ 1/\triangle\ p \ \ldots\ldots\ldots (2.1)$$

Where

K_w = coefficient of water permeability (m/s)

Q = volume of water flowing (m^3)

t = time (s)

l = thickness of penetrated section (m)

A = penetrated area (m^2)

$\triangle$ P = pressure head (m)

2.3.3.1.1.2. Non steady state water permeability

In this case, the depth of water penetration is measured without the water flow necessarily reaching steady state. A succession of water pressure is applied across the specimen as follows (ISO/DIS/7031):

0.3Mpa (3 bar) for the first 24 hour

0.5Mpa (5 bar) for the next 24 hour and

0.7 Mpa (7 bar) for the last 24 hours

At the end of the 72 hour period, the specimens are removed from the rig and split. Just after splitting, the maximum and average depths of penetration are visually observed and measured [35].

2.3.4. Proportioning of Ingredients in Making Concrete

The key in achieving a strong, durable concrete rests in the careful proportioning and mixing of the ingredients. A concrete mixture that does not have enough paste to fill all the voids between the aggregates will be difficult to place and will produce rough, honeycombed surfaces and porous concrete. A mixture with an excess of cement paste will be easy to place and will produce a smooth surface; however, the resulting concrete is likely to shrink more and be uneconomical [36].

There are different methods of mix designing such as: Arbitrary proportion, fineness modulus method, maximum density method, high strength concrete mix design, mix design based on flexural strength, Road note No.4 (grading curve method),ACI Committee 211 method, DOE method, mix design for pumpable concrete. Out of the above methods, some of them are not very widely used these days because of some difficulties or drawbacks in the procedures for arriving at the satisfactory proportions.ACI committee 211 method and DOE methods are commonly used [10].

2.4. Marble and Limestone

2.4.1. Marble and Limestone Definition

The commercial definition of marble refers to all crystalline rocks predominantly composed of calcite, dolomite or serpentine. The root word for marble-marmore- was used by the Italians, an ancient Rome, referring to all hard rocks capable of taking a polish including granite. However, marble in geological usage is a metamorphosed limestone or dolostone whose original texture is obliterated due to intensive re-crystallization [22].

The term limestone is applied to large and petro graphically diverse group of sedimentary rocks which are composed of mainly calcium carbonate ($CaCO_3$) occurring as mineral calcite or aragonite. Around 20 % of all sedimentary rocks are limestone or dolomite or gradation between the two [9].

2.4.2. Geological Formation of Marble and Limestone

Marble is a metamorphic rock produced from limestone by pressure and heat in the earth crust due to geological process [23].Metamorphism involves the alteration of existing rocks by either excessive heat or pressure or through chemical action of fluids. This alteration can cause chemical change or structural modification to the minerals making up the rock. Structural modification may involve the simple re-crystallization of minerals into layers or the aggregation of minerals in to specific areas within the rock [23].

The pressure and heat in the earth‟s crust cause limestone to change in texture and makeup. This process is called re-crystallization. Fossilized materials in the limestone, along with its original carbonate minerals, re-crystallize and form large, coarse grains of calcite [24].

Impurities present in limestone during the re-crystallization period affect the mineral composition of marble which is formed [25]. Impurities incorporated during the original carbonate precipitation especially from the cold marine water solution form characteristics of colors. Accordingly a pure calcite marble is white but tiny amounts of impurities such as iron and magnesium color marble significantly green. Graphite (algae) colors marble dark, pyrite commonly colors marble greenish grey, finely disseminated hematite will color marble pink [22].

At relatively low temperature silica impurities in the carbonate minerals form masses of chert or crystal of quartz. At higher temperature, the silica reacts with the carbonates to produce diopside and forsterite. At a very high temperature rare calcium minerals such as brnite, monticellite and rankinife forms in the marble. If water is present serpentine, talc and certain other hydrous minerals may be produced .The presence of iron, alumina and silica my result in the formation of hematite and magnetite [25].

Limestone is formed by the deposition either of the skeletons of small creatures and or plants (organic limestone) or by chemical precipitation, or by deposition of fragments of limestone rock, on the beds of seas and lakes. Limestone is contaminated to a greater or lesser extent by deposition of sand or clay which is the sources of impurities found in them. Usually there is difference in quality in deposit from layer to the next. The purest carbonates and the most suitable from the production point (cement) of view tend to be the thick bedded type. According to the institute of geological science (UK), limestone with 98.5% or greater calcium carbonate ($CaCO_3$) is classified as of very high purity and less than 85% calcium carbonate as impure [9].

Most carbonate sediments have been produced by biogenic process and consist of the skeleton of carbonate secreting organisms; although some have formed as a result of inorganic chemical precipitation. In geological record there are examples of major carbonate system in which each of these groups has been the dominant carbonate producer. Inorganic carbonates occur as grains and or pore-filling cements precipitated directly from sea water [9].

2.4.3. Chemical and Physical Properties of Marble and Limestone.

2.4.3.1. Chemical Properties of Marble and Limestone.

Chemically, marbles are crystalline rocks composed predominantly of calcite, dolomite or serpentine minerals. The other mineral constituents vary from origin to origin. Quartz, muscovite, tremolite ,actinolite, micro line,chert ,talc, garnet, osterite and biotite are the major mineral impurities whereas SiO_2 ,limonite,Fe_2O_3,manganese,$3H_2O$ and FeS_2(pyrite) are the major chemical impurities associated with marble[25].

Limestone is made up of varying proportion of chemicals such as calcium carbonate ($CaCO_3$),magnesiumcarbonate($MgCO_3$),silica(SiO_2),alumina(Al_2O_3),ironoxide(Fe_2O_3),sulphate (SO_3),and phosphors(P_2O_5) with calcium and magnesium carbonate being the two major compounds. The main impurities in raw limestone (for cement) which can affect the properties of finished cement are magnesia, phosphate, leads, zinc, alkalis and sulfides [26].

Table 2.5: Typical chemical properties of marble and limestone [26][25]

Chemical	Marble (%)	Limestone (%)
Lime(CaO)	28-32	38-42
Silica	3-30	15-18
MgO	20-25	0.5-3
Alumina(Al_2O_3)		3-5
$FeO+Fe_2O_3$	1-3	1-1.5
Alkalis		1-1.5
LOI	20-45	30-32

2.4.3.2. Physical Properties of Marble and Limestone

Physically, marble is re-crystallized hard, compact, fine to very fine grained metamorphosed rocks capable of taking shining polish [25].

All limestone are crystalline but with varying crystal sizes and crystal arrangements [26].

Table 2.6: Typical physical properties of marble and limestone [25][26]

Properties	Marble	Limestone
Hardness	3 to 4 moh"s scale	3-4 moh"s scale
Density	2.55-2.7kg/cm^3	2.5-2.7kg/cm^3
Compressive strength	70-140N/mm^2	60-170N/mm^2
Water absorption	<0.5 %	<1%
Porosity	very low	very low
Weather impacts	resistance	

2.4.4. Uses of Marble and Limestone

Colorless or light colored marble are a very pure sources of calcium carbonate, which is used in a wide variety of industries. Finely ground marble or calcium carbonate powder is a component in paper, and consumer products such as toothpaste, plastics, and paints. Ground calcium carbonate can be made from limestone, chalk and marble; about three-quarters of the ground calcium carbonate worldwide is made from marble. Ground carbonate is used as a coating pigment for paper because of its high brightness and as paper filler. Ground calcium carbonate is used in consumer products such as food additives, in toothpaste, and as inert filler in pills. It is used in plastics because it imparts stiffness, impact strength, dimensional stability, and thermal conductivity. It is used in paints because it is a good filler and extender, has high brightness and is weather resistance [27].The constructional use of marble in most cases is for dimensional stone production although in some places it is also used as raw material in cement production.

Limestone is an input in many industries. It is used in the purification of molten gas, to remove impurities from molten iron, as filler and abrasive in toothpaste, as soil conditioner to neutralize acid soils, as source of calcium in supplements and food additives, to make paper white, in the manufacture of brake pads, in the purification of sugar, in the preparation of wools and dyes, in manufacture of medicinal anti acids, as water neutralizer and as paint additive [28].It is also a major input in construction industry as in the production of cement, production of dimensional and non dimensional stone, as aggregate in road and concrete construction.

2.4.5. Marble and Limestone Deposits in Ethiopia

In Ethiopia marble occurs within the Precambrian basement rocks in all geologic ages; namely, calcite and dolomite marble in the Awata group of Archaean Complex, marble in the Birbir group, Tulu Dimtu group and Mormora group of Late Proterozoic rock of the volcano-sedimentary succession of Pan African age (north, western and southern Ethiopia) [6].

The late Proterozoic to early Palaeozoic marbles of the Tsalient and Tembien groups, are known not to have completed re-crystallization upon transformation of the parent limestone to marble. Such conditions of marble are very ideal for dimension stones and they are commonly found in northern Ethiopia. These rocks reveal both characteristics of limestone and marble, although referred as massive black limestone, Mai Kenetal limestone (800m thick), Assem limestone (300m thick) and commonly occur in association with interbeds of slate, marble, and dolomite. In this connection the Dedikama formation, the youngest of the Proterozoic rock, (1500m thick) consists of creamish to white dolomite. This unit is also found exposed in the Denakil depression [6].

The occurrence of limestone is largely related to two major marine transgression and regression cycles during the Mesozoic era. With regard to the chemical sedimentary rocks / limestone the early transgression had formed the Hamanele, Abay (Goha Tsion) and Antalo formations consisting mainly of limestone, dolomite, gypsum and shale. Subsequently the early regression of the sea towards the end of Jurassic deposited the logoonal facies of Agula formation consisting of black shale, marl and claystone with beds of limestone gypsum and dolomite in Mekale area, Tigray [6].

The second major transgression event during Aptian age also deposited alternating limestone, shale, marls, dolomite and anhydrite. The corresponding regression and subsequent marine situation, late Cretaceous, deposited deterital sediment (sandstone) not chemical sediment (limestone) until the third but less extensive transgression event during Middle to Late Eocene depositing the Taleh formation which consist of anhydrite, limestone and interbeds of shale and gypsum particularly on the eastern extreme of Ogaden basin [6].

2.4.6. Marble Processing in The Ethiopian Marble Processing Enterprise

2.4.6.1. Historical Background

Italian investors primarily established The Ethiopian Marble Processing Enterprise. The establishment dates many years back. It was during the time of Italian occupation, a man known as Signore Loliva Cesare, who erected the first Marble processing plant in Gullelie area, under the name of "Ethio-Marble".The pioneer of the processing plant started producing Marble for the purpose of monuments, tiles and window sills. In 1961 E.C he expanded the production capacity of the plant and the raw materials for Marble products were supplied from Asmara, Mekele and Harar quarries [29].

In 1950"s E.C another Italian investor named Paulo-Mota erected the second plant in Bole area. In 1960 E.C another Italian investor named Signore Frankety erected the third plant in Nifas Silk area. In 1974 during public uprising in the country, the country"s economic systems were changed to command economy; "Nationalization" of Private Enterprises took place, as a rule these three Private Enterprises were nationalized by Proclamation accordingly. The three branches were in corporate under a single Enterprise under the name of "Ethiopian Marble Industry". The organizational structure of the Industry was directly accountable to Building Materials Production Corporation that was in turn directly accountable to the Ministry of Building Construction [29].

After the over throw of the "Derg" regime the Transitional Government of Ethiopia has reorganized the industry,as "The Ethiopian Marble Processing Enterprise". The Enterprise has now three branches namely Gullelie, Bole and Nifas silk [29].

2.4.6.2. Marble Processing and Production

The Enterprise Produces Marble Block from two regional states, namely from Harari National Regional State a place known as "Hakim Gara" quarry it extracts limestone, and from Benshangul Gumuz National Regional State a place known as "Enkonti", "Mora" and Mankush it extracts marble. The Enterprise produces different types of marble block from these three quarry sites. The colour of the marble from these three quarries varies, example Enkunti marble is white gray, and white, while "Mankush" marble is multi-colour, and rose, "Mora" marble mainly has a white colour [29].Annually the three factories are estimated to process marble blocks of 6000 m^3 together.

2.5. Micro Fine Filler in Concrete (in fine aggregate and cement)

2.5.1. General

Micro fines are material passing No. 200 sieve (75µm). Most of the previous work found in the literature on micro fines used as mineral fillers is in regards to self-consolidating concrete (SCC). It has been previously used to optimize particle packing and to modify the flow behavior of the cementitious paste in SCC mixtures. The presence of micro fines in the paste helps reduce the viscosity in the paste. Limestone and dolomite were found to be among the most frequently used mineral fillers for SCC mixtures [17].

One of the biggest concerns when using micro fines is the possibility of clay particles being present, which can weaken the paste-aggregate bond in the concrete. Clays also delay the cement hydration and affect the volume stability of concrete. On the other hand, micro fines like silts can improve the concrete performance. In the case of limestone micro fines, better particle packing can considerably improve stability and workability of fresh concrete. However, in most cases, the addition of a small amount of micro fines can lead to a reduction in workability of fresh concrete [17].

In the past it has been shown by researchers that the addition of mineral fillers (between 7% and 10%) in fine aggregate can improve compressive and flexural strength in concrete. Others found that this improvement can be as much as 30% gain in strength. This is believed to be due to an increase in the density of the paste matrix and interfacial transition zone, once the concrete hardens. The main contribution to strength due to fines occurred during the first 28 days. After the 28-day period, the strength gain was negligible [17].

International center for aggregates research (ICAR) also studied three types of micro fines (two limestones and one granite) as substitution of sand and cement. In the study it was concluded (on report 401/2009) that the use of micro fines allowed the reduction of cement content while maintaining or improving the performance of the baseline mixture. And micro fine additions (cement or sand reduction) improved the hardened properties of the concrete. The compressive strength of the mixtures containing micro fines was higher than for the baseline mixture. The performance of the concrete in shrinkage and permeability was also improved. As for abrasion resistance, the mixtures containing more micro fines were more resistant than the baseline mixture [17].

2.5.2. Trends in Using Micro Fines in Concrete (in fine aggregate)

Conventional wisdom has held that micro fines have higher surface area that results in higher water demand. Higher water demand results in lower strength and higher drying shrinkage [74].For that reason ASTM C33 has limited the amount of fine particles less than 75μm to 5% for concrete subject to abrasion and 7% for other concretes [18].

However, as reported by different researchers, fine particles can act as lubricant and enhance plastic properties of cement paste similar to what fly ash can. Such action decreases the higher water demand due to higher surface area required to achieve a given workability [18].

Many countries allow greater percentage of micro fines in concrete than ASTM C33 specification. Like in Australia normally 10% but 25% if agreed by owners, in France 12 to 18%, in India 15 %(20% if tested), in Spain 15%, in South Africa 10%, in Europe 16 % and in UK 16% of micro fines can be used in concrete production [18].

2.5.3. Theories in Support of Using Micro Fine Filler in Concrete

2.5.3.1. Packing Density

The grading of aggregates can have a great influence on the performance of a concrete mix is actually well known long time ago [20]. It is only that many parameters (the various size fractions of the aggregate) are needed to describe the grading and the effects of the various parameters are often blurred by the interaction between the various parameters involved. Nevertheless, it is nowadays very clear that the single most important parameter influencing the performance of concrete is the packing density of the aggregate.

The packing density of a given aggregate or a given lump of solid particles is the ratio of the volume of solids to the bulk volume of the solid particles. Since the bulk volume is equal to the volume of solids plus the volume of voids, a higher packing density means a smaller volume of voids to be filled and vice versa. With the paste volume fixed, the increase in packing density of the aggregate could be employed to increase the workability of the concrete at the same water/cementitious (w/cm) ratio or increase the strength of the concrete by reducing the water/cementitious ratio while maintaining the same workability. Apart from increasing the excess paste at a given paste volume to improve the workability and/or strength of the concrete, the increase in packing density of the aggregate could also be employed to improve the dimensional stability of the concrete. In a concrete mix, it is the cement paste that generates heat of hydration causing thermal expansion/contraction during the early age and shrinks when subjected to drying in the longer term. Hence, the larger the paste volume is, the larger would be the changes in dimension of the hardened concrete due to early thermal expansion/contraction and long term drying shrinkage. The heat of hydration and drying shrinkage of a concrete are dependent also on the water/cementitious ratio, both being larger at higher water/cementitious ratio. The reduction in paste demand due to a higher packing density of the aggregate would for the same workability allow the use of a smaller paste volume at fixed water/cementitious ratio or a lower water/cementitious ratio at the same paste volume, either of which would significantly improve the dimensional stability of the concrete [20].

The concept of packing density can be extended to apply also to cementitious materials, which may include cement and other supplementary cementitious materials, such as pulverized fuel ash (PFA), ground granulated blast-furnace slag (GGBS) and condensed silica fume (CSF) etc. Drawing analogy to the previous case of packing aggregate particles, the packing density of the cementitious materials should have similar effect on the water demand and the flow ability of the cement paste. The different types of cementitious materials are generally of different sizes. By mixing appropriate proportions of different cementitious materials together, the medium size particles will fill up the gaps between the larger size particles and the smaller size particles will fill up the gaps between the medium size particles and so forth. Hence, blending cementitious materials of different sizes together could increase the packing density of the cementitious materials and reduce the water demand [20].

2.5.3.2. Incomplete Hydration of Cement in High Strength Concrete

In concretes with low w/c ratio (<0.38), hydration of the cement will be incomplete; as there is insufficient pore space within which the hydration products can deposit. Thus in these concretes a portion of the relatively expensive cement is potentially being wasted and serving only as reinforcing material [19].

Thus it is suggested by many researchers to replace the unhydrated cement with cheap inert fillers to produce economical concrete.

2.6. Limestone (Calcium Carbonate) Filler in Cement and Concrete

2.6.1. General

Calcium carbonate filler**,** often called limestone filler, is normally less expensive than Portland cement and can cost effectively replace a part of the powder content in most concretes [30**].**

Traditional use of Calcium carbonate originates from France and has been in use for more than 25 years [30].In Europe, a number of countries allowed different percentages of limestone prior to adoption of EN 197-1. The current EN 197-1 (2000) allows all of the 27 common types of cement to contain 5% minor additional components, which most typically are either limestone or cement raw meal. As well, 6 types of cement allow higher amounts of limestone in two replacement level ranges, CEM II/A-L and CEM II/A-LL (6-20% limestone), CEM II/B-L and CEM II/B-LL (21-35% limestone) and CEM II/A-M and CEM II/B-M in addition to the 5% minor additional components. The difference between the –L and the – LL designations are based on different qualities of the limestone used. For both L and LL, $CaCO_3 \geq 75\%$ and clay content ≤ 1.20g/100g. The difference is in the allowable total organic carbon content: Type LL restricts total organic content ≤ 0.20% by mass while Type L restricts total organic content ≤ 0.50% by mass [31]. 5% limestone addition to Portland cement is also allowed in the U.S. [31].

2.6.2. Production and Reaction of Limestone Cement

Limestone cement can be produced by inter grinding, blending or by addition at the time of mixing concrete. Inter grinding of limestone has several benefits. Limestone is a softer material than clinker and therefore takes less energy to grind to the same fineness [31].

The reactivity of limestone has been debated, while most researchers have previously believed that limestone serves as inert filler, research shows that limestone does react to a limited extent. As the limestone particles become finer, this reaction is more likely. Researchers found that at low concentrations limestone (calcite) reacts completely to form various carboaluminate phases. The extent of limestone‟s reactivity is controlled by the amount of sulphate in the system. As the sulphate content increases, the likelihood of unreacted calcite increases. Differences in the types and amounts of hydration products have been observed between Portland and limestone cements. There is much agreement that limestone reacts primarily with the C_3A component of the cement to form carboaluminates at the expense of hydrates. It has been suggested that some $CaCO_3$ can be incorporated in calcium silicate hydrate (CSH) formed by C_3S. However, the formation of ettringite is under debate. Production of calcium hydroxide (CH) seems to be enhanced at early ages partially due to dissolution of limestone and also due to limestone‟s ability to act as nucleation sites. Different authors found that the CH crystals forming in limestone cements to have different morphology than those in Portland cements [31].

2.6.3. Effects of Limestone (Calcium Carbonate) Filler on Cement Properties

2.6.3.1. General

In most cases limestone filler have an effect on the cement properties due to their fineness. Inclusion of an inert very fine powder will significantly accelerate the hydration of alite and aluminates of the cement because the particles act as nucleation sites for the formation of the hydration products .Another effects of finely divided additions is their action as filler between the cement grains producing a denser paste and densifiying the interfacial zone between the aggregate and cement paste [21].

In a test series with additions of limestone of increasing fineness, researchers found a relatively greater increase in 2 day strengths compared with 28-day strengths, attributed to the filler effect of the limestone. Some investigators also observed that addition of 5% and 25% limestone enhanced formation of calcium hydroxide at early ages in cements due to the provision of nucleation sites by limestone for the growth of calcium hydroxide. Improved strength development from additions of limestone with varying fineness was also observed. Thus, inclusion of appropriate amounts of a very fine powder will enhance the performance of most cement, despite the dilution [9].

2.6.3.2. Consistency

The effect of limestone powder on the water requirement of OPC and blended cement has been studied extensively and majority of findings are in favor of a better workability of mortar and lowering the water requirement for neat paste containing limestone. The improvement in the workability of paste and mortar is due to suitable texture fineness and particle size distribution of cement containing limestone.

As reported after investigation carried out on consistency of cement with limestone powder addition with various fineness and particle size distribution similar to OPC, the apparent viscosity of cement paste is decreased with the increasing amount of limestone. Other researchers also used three cements of different fineness with different quantity of limestone from 0-15% by weight and found that limestone addition up to 15% decreases yield point values, especially for finer cements and increases slightly the plastic viscosity .From the results it was concluded that lubricating power of very fine limestone particles was the most possible reason for their behavior because of difference in grind-ability of limestone and cement [9].

Limestone have practically no effect on consistency of cement up to 5% replacement but at 7% and 10 % replacement level there is 1-2% reduction in water requirement of cement. However the water reducing effect decreases with the higher fineness of limestone [9].

2.6.3.3. Soundness

The effect of calcareous addition on the autoclave expansion of OPC has not been studied extensively. The recent findings show that the addition of calcareous material (limestone) up to the range of 5-7% in cement mortar has small influence on shrinkage as compared to siliceous additives. From the results of autoclave and Le-Chatelier expansion as observed by investigators there is no remarkable effect on the soundness of OPC paste with up to 10% replacement by additives [9].

2.6.3.4. Setting Time

In regard to the effect of limestone on setting times of cement, the general consensus is that the fineness of limestone is a factor influencing setting time of cement pastes. However, the magnitude of this effect differs among various studies. Some researchers investigated cement pastes of different fineness and C_3S contents at 0% and 5% limestone replacements. Initial and final setting times were found to decrease as fineness increased. The decrease was more pronounced in cements with low C_3S. Similarly others found that increasing limestone additions decreased the setting time of cement pastes. On the other hand, other researchers found that increased fineness gave longer initial setting times at 20% limestone replacement [31].

2.6.3.5. Hydration

Many research papers on influence of limestone powder on hydration of Portland cement have reported that the C_3S hydration rate is accelerated when the amount and fineness of $CaCO_3$ is increased. This is due to the fact that they generate a large number of nucleation sites for precipitation of the hydration products [9].

Some researchers investigated hydration of cement pastes at various w/c ratios (0.25 to 0.50) with approximately 10% and 20% limestone replacements. It was found that the degree of hydration was markedly more rapid during the first 7 days in the higher w/c ratio pastes containing limestone. At lower w/c ratio (~0.30), the differences were not as noticeable. However, it must be noted these pastes were designed to have similar strength. Similar results were observed in concrete mixtures at 0.34 and 0.50 w/c ratio containing approximately 10 and 20% limestone. For both water to cement ratios investigated, the addition of limestone increased the degree of hydration at all ages. For ternary blends of cement, fly ash and limestone, chemically combined water was found to increase with increasing amount of limestone (decreasing fly ash, as total of these was kept at constant 20% replacement) in OPC pastes. However, for sulphate resistant cements, increased hydration was observed up to 10% limestone with minimal differences at higher amounts of limestone [31].

2.6.3.6. Compressive Strength

Some observers found that addition of limestone powder into cement paste and mortar increases the strength at early ages without changing the workability of mortar. The increase in strength is directly related to the rate of hydration of cement by the addition of limestone [9].

For a given cement strength the maximum addition of limestone varies with the type of clinker and with its fineness. For a given clinker and a given limestone, the more limestone added the higher clinker fineness should be to produce a cement of the same strength [41].

According to some investigators, irrespective of grinding method, inter-grinding or separate grinding of limestone and other materials, up to 5%,the strength of cement at 3 and 7 days were slightly higher than the pure ordinary Portland cements. The decrease of strength at 28 and 91 days is found nearly linear to the amount of limestone [9].

Depending upon the source of limestone, undesirable effects on the strength was also observed. In every case, decrease in the strength caused by limestone at the age of 91 days seems to be smaller than at the age or 28 days. Findings of research works on the strength development show that when the percent of substitution of limestone in OPC increases, the compressive strength of resultant cement decreases [9].

Researchers also observed that blending of Portland cement with 10-40% finely ground limestone improves the early strength. At 10 and 20% addition of limestone in cement there was an increase of 145% and 135% in 3 days compressive strength. At 7 days, it was also maximum for 10% substitution level. The 28 days compressive strength at 12% addition level was equivalent to control OPC, but at higher substitution level the same strength was less than the control cement [9].

It has been observed that the strength of cement with higher aluminates (C_3A-13.2%) was not lowered even at 30% addition of fine carbonates, while the cement having C_3A content at 3-5% can accommodate 20% of carbonate addition without altering the strength characteristics of original cement [9].

2.6.4. Effects of Limestone (Calcium Carbonate) on Concrete Properties

2.6.4.1. Workability

In regards to the effect of limestone additions on water demand and workability, there are conflicting results in the published literature. Much of these effects can be related to the particle size distribution of the limestone in relation to the cement. Generally, fine limestone particles can enhance the overall particle packing of the binder materials resulting in less space for water between the solid grains. Some researchers found that decreasing the average particle size of limestone used as a partial replacement for cement gave better early-age rheological properties. [31].Above a certain proportion natural impurities in limestone can increase the water demand [41].

Less research has been carried out on the effects of limestone additions in concrete concerning water demand. Some found that concrete slump decreased (less workable) with coarser limestone than with finer particles. Decreased workability was also observed with increasing limestone additions by increased admixture dosages to achieve the target slump. Other determined that 0.01 increment in w/c ratio was required to achieve the same slump from 0% to 5% limestone addition and another 0.01 increase for limestone addition from 5% to 25%. [31].

2.6.4.2. Compressive Strength

The strength of concrete produced with limestone cement is strongly influenced by the quality of the limestone used, the manufacturing process (blending versus inter-grinding) and the final particle size distribution of the cement. Limestone is softer than Portland cement clinker and will, therefore, be finer than the clinker if the two products are ground together. For cements of equal surface area (Blaine), the clinker particles in Portland-limestone cement (PLC) will be coarser than those in Portland cement (PC)[31].

Some researchers compared a series of cements with limestone contents of 0, 3, 5.5 and 8% prepared at equal Blaine versus at equal sub-45 micron (# 325) value. In these tests a limestone with 85% $CaCO_3$ was used together with a Type II low-alkali clinker with a C_3A content of 5.1% and the clinker, gypsum (all cements contained 2.5% SO_3) and limestone were ground together in a laboratory ball mill. These data show that comparable strengths can be obtained provided that Portland limestone cement (PLC) is ground to a higher surface area or equal sub-45 micron (# 325) sieve value. Limestone additions up to 5% may actually increase early-age strength as a combined result of improving particle packing, increasing the rate of cement hydration; and early production of calciumcarboaluminate. Even when ground limestone is blended with Portland cement(PC) (as opposed to inter-grinding), the strength is relatively unaffected up to 5% limestone .At higher replacement levels the loss of strength due to dilution must be compensated by finer grinding[31].

Other researchers compared three cements from the same plant with 0, 8.3 and 18.1% inter-ground limestone having Blaine finenesses of 317, 372 and 420 m^2/kg, respectively. Concretes (w/c = 0.5) produced with these cements achieved 28-day, water-cured compressive strengths of 40.2, 38.1 and 36.3 MPa (for 0, 8.3 and 18.1% limestone, respectively).Early-age strengths were increased in the concretes produced with the limestone cements and, as a result, the 28-day strengths of concretes that were air-cured after 1 day, were greater for the mixes with PLC [31].

In summary, with regards to the impact of PLC on the compressive strength of concrete, the published data would seem to support the conclusions that the appropriate choice of clinker quality, limestone quality, limestone content and cement fineness can lead to the production of a limestone cement with the desired properties" at least for cements with up to 15% limestone [31].

2.6.4.3. Tensile Strength, Flexural Strength and Modulus of Elasticity

Studies of tensile (cylinder splitting) and flexural strength, and modulus of elasticity have been made by a number of authors. Generally the trend in behavior is the same as that observed for compressive strength and predictive equations used to estimate these properties from the compressive strength are valid for concrete produced using Portland Limestone cement [31].

2.6.4.4. Permeability

Some researchers measured the gas permeability, water permeability, sorptivity, and porosity of concretes produced with 7 different cements. The cements were produced by inter-grinding clinker (7.3% C_3A), limestone of high purity (95.5% $CaCO_3$) and gypsum (5% by mass of clinker) in a pilot plant ball mill. The cements differed in the quantity of limestone and the fineness of the inter-ground cement. The cements were used to produce concrete samples which were cured for 28 days prior to conducting the tests. In general, the concretes produced with PLC have higher gas permeability coefficients than the PC concrete, with the exception of the concrete produced with the PLC with 35% limestone, which recorded the lowest gas permeability value. On the other hand, the PLC concretes showed reduced permeability to water and lower water sorptivity values. The porosity of the concrete was unaffected by the presence of up to 15% limestone in the cement, but increased with higher limestone contents. The authors concluded that overall the PLC concrete had "competitive properties" with the PC concrete [31].

Other researcher conducted oxygen permeability tests on concretes (w/c = 0.60) produced with a range of different cements. Five different Portland cements were used in this program. One of these was inter-ground with 5 and 25% limestone; the remainder was blended with 5 or 25% ground limestone. One of the cements was blended with 30% fly ash and another was inter-ground with 28% fly ash. After stripping at 24 hours, concrete samples were stored either in water or air until 28 days, after which all samples were further conditioned in air at 20^oC and 65% relative humidity (RH) until test at 100 days. The results have been averaged for all mixes produced with the same limestone content. It is evident that the permeability decreases with increasing limestone in the cement; however, differences are relatively small compared with the reductions due to extended curing [31].

2.7. Some Previous Studies of Using Marble Waste as Filler in Cement and Concrete

Marble powder as raw material to cement production was studied by National council for cement and building material, Bombay [1] ;and it was reported that it was achieved by the study that marble waste powder can be used as cement raw mix component from 5 to 15%.

Valeria & et al [2], conducted compressive strength test of mortar with percentage replacement of cement by marble waste powder; and it was reported that compressive strengths of mortars decrease with increment of percentage of cement by marble powder. It was studied by Valeria Carinaldesi & etal [20] that a mixture made of water, marble powder and hydrated lime $(CaOH)_2$ and cured in sealed air-free environment, was not able to harden after 28 days of observation which implies that marble powder is not pozzolanic.

In a study by A.K.misrak & Renimate [3], it was reported that at w/c ratio=0.537 workability of concrete decreases as percentage of sand is substituted by marble powder. But in another study by Hanifi Binic, et.al [4] it was reported that concrete made by replacement of sand by marble dust up to 15% had good workability comparable to that of conventional concrete.

In a study by A.K.misra & Renu Mathur [3], it was reported that compressive strength, flexural strength and abrasion resistance of concrete made by percentage substitution of sand by marble powder showed compressive strength, flexural strength and abrasion resistance increment up to 40% substitution. The result of the compressive strength is supported by a study conducted by Hanifi Binic & etal [4], but the study was up to 15%.In a study by Valeria and etal [20], it was also reported that marble waste powder can be used as filler and helps to reduce the total voids content in concrete, consequently, this contributes to improvement of strength of concrete.

Hanifi,Binic,& etal[4] also showed that abrasion resistance of concrete made by percentage substitution of sand by marble waste powder was comparable with concrete without marble powder.

In the same study, increment of percentage of substitution of sand by marble dust caused a significant increment in the sodium sulphate resistance of concrete whereas water penetration depth of concrete with marble dust at 15% substitution was found considerably less than that of concrete with 0% marble powder.

CHAPTER THREE

MATERIALS USED IN THE RESEARCH

3.1. Introduction

In this chapter, the materials used for the investigation are described with respect to their sources and relevant physical and chemical properties. All laboratory investigations on the materials used in studying the properties of marble waste powder blended cements are carried out in Mugher cement factory quality control assurance department; whereas the properties of concrete made by incorporation of marble waste powder ingredient is studied in Addis Ababa University, Civil Engineering Department, material lab.

3.2. Materials Used in Studying the Properties of Marble Waste Powder Blended Cements

3.2.1. Clinker

For the production of laboratory cements, clinker from Mugher cement factory was chosen. For this test purpose, the sample of the clinker was collected from the clinker silo which was collected after passing the full clinkerization process by controlling the raw materials in such a way that their chemical composition were within the norm of the factory.

To have consistent product and to keep the quality of cement, the factory used to control the raw material mix by chemical analysis and computerized control system. For this purpose, from experience, it sets its norm chemical range for each raw material such that the clinker is expected to be consistent and be within the standard. It corrects any deviation, of the raw material chemical composition from the range, by adjusting the raw material proportion and or using corrective raw materials. The clinker used for the test was also produced from raw materials whose chemical composition was within the norm of the factory.

The sample of the clinker was tested for its chemical and mineralogical composition and the test results are shown in Table 3.1 and 3.2 below.

Table 3.1: Chemical composition of Mugher clinker used for the test

Chemical composition	Test result (%)
SiO_2	20.03
Fe_2O_3	3.73
Al_2O_3	5.94
CaO	66.31
MgO	1.07
SO_3	1.14
K_2O	
Na_2O	
LOI	0.08
IR(insoluble residue)	0.12
F-CaO(free calcium)	1.94
$CaCO_3$	77.87

Table 3.2: Mineralogical composition of Mugher clinker used for the test

Mineralogical composition	Test result (%)
C_3S	61.25
C_2S	11.23
C_3AF	9.42
C_4AF	11.38

3.2.2. Gypsum

The gypsum used for the test was also taken from the source of Mugher cement factory. Before it was used in the Portland cement production, the gypsum was crushed in raw material grinding mill and dried in the lab. The chemical composition of the gypsum was tested to check its conformity to the norm of the factory. The test results are shown in Table 3.3 below.

Table 3.3: Chemical composition of gypsum used for the test

Chemical composition of gypsum	Norm (%)	Sample gypsum (%)
H_2O		10
SiO_2	0.2-15	16
Fe_2O_3	0.5-1.5	1.2
Al_2O_3	1-4.3	3.5
CaO	28-34	30
MgO	0.6-3	0.45
SO_3	28-43	35
K_2O	<=0.3	Negligible
Na_2O	<=0.3	Negligible
LOI	12.6-24.5	9

3.2.3. Marble Waste Powder

Before using marble waste powder for the test, four samples, collected on different times from the three factories of The Ethiopian Marble Processing Enterprise were examined for their fineness and chemical composition. The test results are shown in Table 3.4 and 3.5 below.

Table 3.4: Chemical composition of marble waste powder samples

Chemical composition	**Marble waste 1 (%)**	**Marble waste 2 (%)**	**Marble waste 3 (%)**	**Marble waste 4 (%)**
SiO_2	0.62	1.08	3	1.14
Al_2O_3	0.16	0.4	0.25	0.2
Fe_2O_3	0.10	0.12	0.56	0.24
CaO	54.91	53.79	52.45	53.57
MgO	0.8	0.8	1.28	1.12
$CaCO_3$	98	96	94	95.13
LOI	43.25	43.41	41.54	42.54

Table 3.5: Fineness of marble waste powder samples

Physical property	**Marble waste 1**	**Marble waste 2**	**Marble waste 3**	**Marble waste 4**
Fineness (average of 5 tests) (Blaine)	3571cm^2/g	4843cm^2/g	4843cm^2/g	4843cm^2/g

Then two samples, one with fineness of 3571cm^2/g(sample 1) and another with fineness of 4843cm^2/g (sample 2) were selected and used for the test as all the samples are similar in chemical composition.

3.2.4. CEN Standard Sand

The sand used for the study to determine the strength of cement was CEN standard sand with well graded rounded particles and has a Silica content of 98% as specified in EN 196-1 standard requirement. This CEN sand is delivered in plastic bags with a content of 1350 gm .It is imported from Germany by the Mugher cement enterprise for quality control of cement production.

3.2.5. Chemicals

For determination of the chemical and mineralogical composition as well as sulphate and insoluble residue, different chemicals were used as per the specified method of testing cement based on the European standard EN 196.2.

3.2.6. Water

Throughout the investigation, tap water supplied for drinking consumption at Mugher was used for curing the hardened mortar samples. For all physical and chemical analysis distilled water was used.

3.3. Materials Used in Studying Concrete Properties

3.3.1. Cement

For studying the effects of marble waste powder on the properties of concrete, it was proposed to use Mugher OPC; however as Mugher was not producing OPC and also as other factories were concentrating on production of PPC, it was difficult to get any OPC in and around Addis Ababa during the studying period. Therefore it was a must to search and use another comparable cement that Mossobo OPC was collected from Mekele and was used for the experiment.

That is, for all concrete specimens casted for the investigation, cement of Mossobo Ordinary Portland, which was manufactured according to Ethiopian standard ES-1177-1-2005 and European standard EN-197-1-2000, was used. Its typical chemical and mineralogical compositions are shown in Table 3.6 and 3.7 below:

Table 3.6: Typical chemical composition of Mossobo OPC [35]

Chemical composition	Percentage by weight
SiO_2	20.05
Fe_2O_3	3.70
Al_2O_3	4.75
CaO	63.94
MgO	1.31
SO_3	2.41

Table 3.7: Typical mineralogical composition of Mossobo OPC [35]

Mineralogical composition	Percentage by weight
C_3S	60.41
C_2S	13.19
C_3A	6.32
C_4AF	11.27

Its fineness as measured in the lab, by Blaine, was 4320 cm^2/g.

3.3.2. Aggregates

Throughout the experiment, river sand and basaltic crushed stone from local market, with the following physical characters, were used as fine and coarse aggregate respectively.

3.3.2.1. Silt Content of Fine Aggregate

The presence of dust, loam and clay materials with sand decreases the bond between the materials to be bound together thereby decreases the strength of concrete besides decreasing the quality of concrete. Accordingly, the sand for the experiment was tested for silt content and was found to have 13% silt content .This is above the maximum value recommended by Ethiopian standard. Therefore, the sand, before used in all tests, was washed until clear water came out.

3.3.2.2. Gradation of Fine and Coarse Aggregate

Aggregate grain size distribution or gradation is one of the properties of aggregates which influence the quality of concrete. Therefore, fine aggregate and coarse aggregate with gradation satisfying the grading requirement of Ethiopian standard (ES C.D3.201 as shown in Table 3.8 and 3.9 respectively) were used throughout the experiment.

Table 3.8: Gradation of fine aggregate used for the test

Sieve size	Weight Retained (gm)	Percentage retained	Cumulative coarser (%)	Cumulative passing (%)
9.5mm	0	0	0	100
4.75mm	17	2.53	2.53	97.47
2.36mm	30	4.48	7.01	92.99
1.18mm	95	14.16	21.17	78.83
600µm	158	23.55	44.72	55.28
300µm	186	27.72	72.44	27.56
150µm	126	18.78	91.22	8.78
Pan	53	8.78	100	
		FM=	245.35/100=2.45	

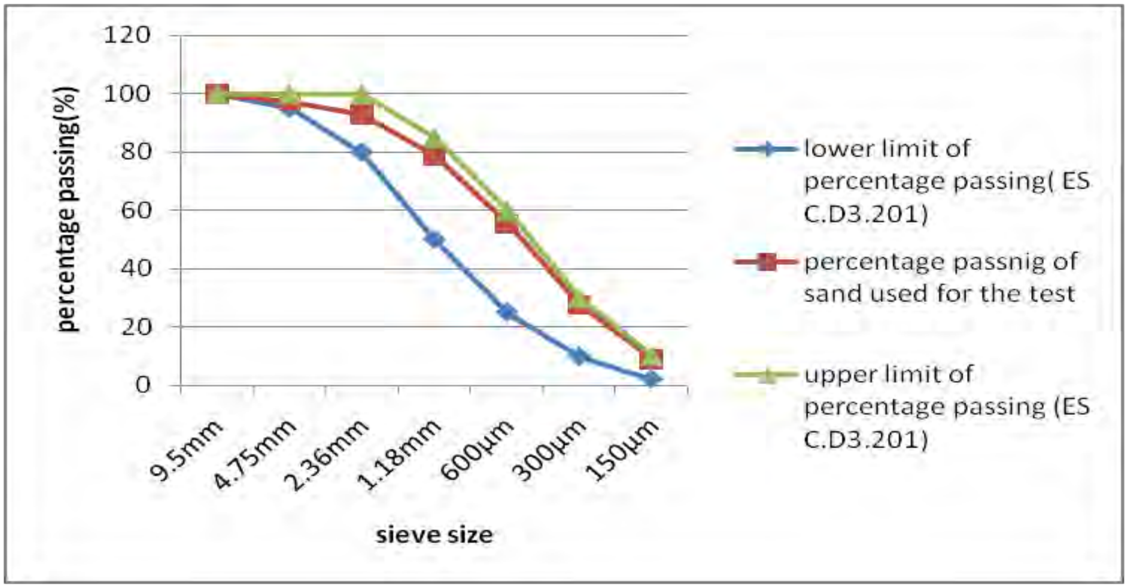

Fig 3.1: Gradation of sand used for the test

Table 3.9: Gradation of coarse aggregate used for the test

Sieve size (mm)	Weight retained (gm)	Percentage retained	Cumulative coarser (%)	Cumulative passing (%)
	0	0	0	100
37.5	0	0	0	100
25*	901	11.33	11.33	88.67
19.5	1495	18.79	30.12	69.88
12.5*	3144	39.53	69.65	30.35
9.5	1379	17.34	86.99	13.01
4.75	927	11.65	98.64	1.36
Pan	107	1.36	100	

*intermediate sieve

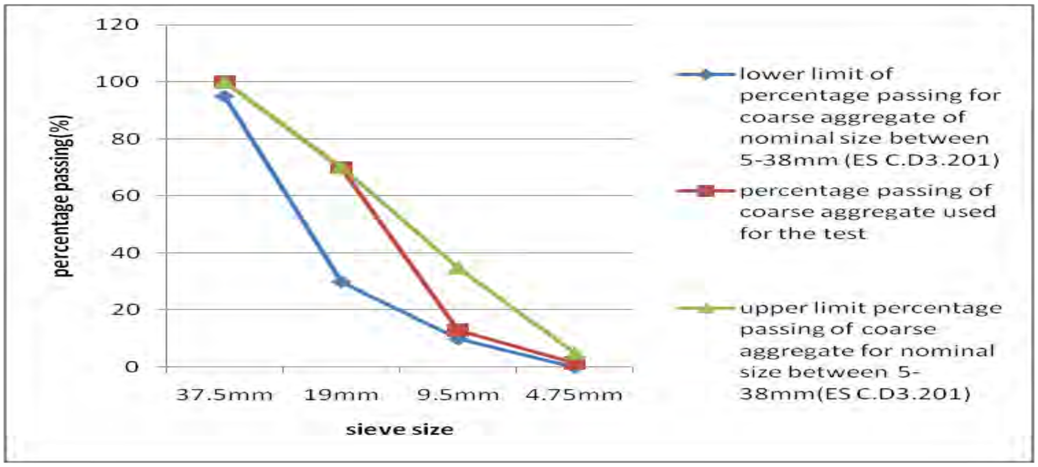

Fig 3.2: Gradation of coarse aggregate used for the test

3.3.2.3. Unit Weight, Specific Gravity and Absorption Capacity of Aggregates

As unit weight, specific gravity and absorption capacity affect the type and quality of concrete and as such parameters are input for mix designing, these parameters were determined for both fine and coarse aggregate. The determined values are shown in Table 3.10.

Table 3.10: Physical test results of aggregates used for the test

Type of aggregate	Unit weight (kg/m^3)	Specific gravity (Bulk SSD)	Absorption capacity (%)
Fine aggregate	1484.86	2.77	7.82
Coarse aggregate	1484.80	2.72	1.93

3.3.3. Marble Waste Powder

In this test, commercially called marble waste powder but geologically limestone mixed marble waste powder, marble processing factory by-product, from The Ethiopian Marble Processing Factory, (Sample 4 type as indicated in Table 3.4 with Blaine fineness value of 4843cm^2/g) was used as cement and sand replacing filler.

Although four samples from the three sources were taken, only sample 4 was used in this experiment since sample 2, 3 and 4 were similar. Sample one was dropped as it was coarser than the cement used for the test.

3.3.4. Water

Clean tap water was used for washing aggregates, and mixing and curing of concretes.

3.3.5. Chemicals

Water reducing admixture, SP 1, which is manufactured in Ethiopia by Licon Manufacturing PLC, was used during mixing for high strength concrete samples as per the manufacturer‟s instruction.

CHAPTER FOUR

EXPERIMENTAL PROGRAM

4.1. Introduction

The main objectives of the experimental program are to study the effects of using marble waste powder as cement replacing filler on the physical and chemical properties of cement, and to study the effects of using marble waste powder as cement or sand replacing filler on the performance of concrete. To achieve these objectives, two major experiments were designed.

The first experiment (experiment one) was done to determine the effects of replacing part of Ordinary Portland cement with marble waste powder on various properties of cement such as water requirement or normal consistency, setting time, soundness, compressive strength and flexural strength.

Following experiment one, another experiment (experiment two) was performed to determine the effects of replacing part of cement and sand with marble waste powder on concrete performance such as workability, strength and permeability.

4.2. Experiment One

Experiment one, which consists of preparation of marble waste powder, determination of fineness of marble waste powder, choosing type of cement and fineness of cement for the experiment, production of cement, preparation of blended cements, different physical and chemical tests of cement and preparation and test of mortar and cement pastes, was designed to determine the effects of replacing part of Ordinary Portland cement with marble waste powder on various properties of cement.

4.2.1. Preparation of Marble Waste Powder

The marble waste originally was discharged from the factory in slurry form and was very wet during collection. This required drying the slurry to get it in powder form. Therefore, the marble slurry collected from the factory was dried by sun light for more than 15 days (due to the winter season) until its water content is nil.

The interest of the researcher was to use the marble waste powder with its original (natural) fineness. However as the powder comes out in slurry form from the factory, drying turns it to large conglomerate grain form than to powder form; this required a certain manual grinding to get its natural (original) fineness.

Therefore the dried conglomerate grain was ground manually by local traditional stone mill and its fineness was determined before blending with cement.

4.2.2. Determination of the Fineness of Marble Waste Powder

After grinding, the fineness of the four marble waste powder samples was tested for fineness by Blaine air permeability apparatus. And it was found that one sample had a Blaine fineness of 3571 cm^2/gm whereas the three samples had Blaine fineness of 4843 cm^2/gm.

4.2.3. Choosing the Type and Fineness of Cement

As the interest of the researcher was to use the marble waste powder with its own original fineness, the fineness of the cement in the research was determined with respect to the fineness of the waste powder with the idea that the cement would be coarser than the filler powder so that the powder would have filler effect. With this interest the cement for the research was ground to Blaine of 3113 cm^2/gm which is under the range of General Purpose Ordinary Portland cement fineness.

In practice (in Mugher factory) OPC cement is ground coarser than PPC cement. This makes the researcher expect the marble waste powder would have better filler effect on OPC than PPC that OPC cement was used for research.

4.2.4. Production of Cement

For producing cement for the research, clinker passing the normal controlling step and composed of raw materials with chemical composition within the range of the norm of Mugher cement factory was taken and ground with 5% gypsum which fulfills the norm of chemical composition range of the factory. The clinker and gypsum was ground in a mill to fineness of 3113 cm^2/gm.

4.2.5. Preparation of Blended Cements

After Ordinary Portland cement was produced to the required fineness in the mill, and after the marble waste was prepared as described in section 4.2.1, two groups of blended cements were prepared by mixing marble waste powder with 5, 10, 15, 20% addition of the mass of Ordinary cement. This blending was done in dry condition by rotary mixer such that the distribution of the filler will be homogenous and uniform.

The first group of blended cements (5 in number) ,were prepared by blending Mugher OPC with marble waste powder of Blaine fineness of 3571 cm^2/gm from 5 to 20 % ranges with 5% increment as shown below in Table 4.1.

Table 4.1: Proportion of blending of marble waste powder, for fineness of 3571 cm^2/gm, with OPC

S.No	**Code**	**Mugher clinker (%)**	**Gypsum (%)**	**Marble waste powder (%)**
1	MOPC	95	5	0
2	MP5	90	5	5
3	MP10	85	5	10
4	MP15	80	5	15
5	MP20	75	5	20

The second group of blended cements (4 in number) were prepared by blending Mugher OPC with marble waste powder of Blaine fineness of 4843cm^2/gm from 5 to 20% ranges with 5% increment as shown below in Table 4.2.

Table 4.2: Proportion of blending of marble waste powder, for fineness of 4843 m^2/gm, with OPC

S.No	**Code**	**Mugher clinker (%)**	**Gypsum (%)**	**Marble waste powder (%)**
1	MLP5	90	5	5
2	MLP10	85	5	10
3	MLP15	80	5	15
4	MLP20	75	5	20

Note: The description of the blending code is:

MOPC indicates control cement prepared by Mugher OPC without filler.

MP5 indicates Mugher OPC cement blended with 5% marble waste powder of 3571 cm^2/gm fineness.

MP10 indicates Mugher OPC cement blended with 10% marble waste powder of 3571 cm^2/gm fineness.

MP15 indicates Mugher OPC cement blended with 15% marble waste powder of 3571 cm^2/gm fineness.

MP20 indicates Mugher OPC cement blended with 20% marble waste powder of 3571 cm^2/gm fineness.

MLP5 indicates Mugher OPC cement blended with 5% marble waste powder of 4843 cm^2/gm fineness.

MLP10 indicates Mugher OPC cement blended with 10% marble waste powder of 4843 cm^2/gm fineness.

MLP15 indicates Mugher OPC cement blended with 15% marble waste powder of 4843 cm^2/gm fineness.

MLP20 indicates Mugher OPC cement blended with 20% marble waste powder of 4843 cm^2/gm fineness.

4.2.6. Preparation of Specimens

As strength is the main quality controlling parameter for cement, different specimens were prepared for studying the strength. For all mixes the European Standards and with particle size distribution and moisture content which comply with the specified standard of EN 196-1:1994 was used. The test specimens for strength tests were then cast in steel mold with 40mmx40mmx160mm prism in two layers and compacted on jolting apparatus with 60 jolts for the first layer and then compacted the second layer with a further 60 jolts. All specimens were prepared with one part cement to three parts of standard sand proportioned by weight with sufficient water.

4.2.7. Curing Condition

After casting, primarily all mortar blocks were placed in a shelf with relative humidity of above 65% and room temperature of between 20-22^{0}c to enable the mortars achieve enough strength for water curing by ensuring that moisture is retained and not lost rapidly. Then all the mortar blocks were immersed in a water curing pond until testing period. Each of the blocks were marked using permanent ink marker in each case to clearly show the percentage cement content, date and time of production and an identification number.

4.3. Experiment Two

Experiment two, which consists of determination of the physical parameters of fine and coarse aggregate, mix designing, concrete specimens preparation and tests of fresh and hardened concrete cubes and beams, was designed to determine the effects of replacing part of cement and sand with marble waste powder on concrete performance.

4.3.1. Determination of Physical Parameters of Aggregates (fine and coarse)

Aggregates are important constituents in concrete. The mere fact that aggregates occupy 70-80 percent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable. The depth and range of studies that are required to be made in respect of aggregates to understand their widely varying effects and influence on the properties of concrete cannot be underrated[10].As aggregates are natural materials their proprieties vary in different extent that concretes of different aggregates vary accordingly. Different physical parameters of aggregates are required to be within a certain limit by different standards so that the concrete from that aggregate will give the intended performance. Some physical parameters are also important as an input in mix designing. Therefore, the following properties of aggregates were tested and determined.

1. Gradation of fine and coarse aggregates by sieving with procedures as indicated in construction materials laboratory manual [14]. From this test the gradation of both coarse and fine aggregates were found to be within the standard requirement of ES C.D3.201.

2. Silt content of fine aggregate: for determination of silt content by mass, a sample of fine aggregate was taken and it was dried in an oven at 105 ^{o}c for 24 hours. It was then sieved on a 1.18mm sieve. The material passing was weighed and its mass was recorded as m1.It was then thoroughly washed on a 75µm until clear water came out, and again dried in the oven at 105 ^{o}c for another 24 hours. Its final mass was then recorded as m2.The silt content was then calculated as

Silt content= (m1-m2)/m1*100.

By this test, the silt content was found to be 13% which is above the limit recommended by Ethiopian standard; therefore the sand was washed before use.

3. The specific gravity and absorption capacity of fine and coarse aggregates were determined by methods and procedures indicated in construction materials laboratory manual [14] as they are inputs for mix designing. The unit weights of the aggregates were also determined.

4.3.2. Mix Designing and Trial Mix Preparation

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible.

For this experiment, design mix is done using DOE method for two classes of concrete (C-25 and C-50).The proportion of the materials as per the design is given in Table 4.3 below.

Table 4.3: Proportion of materials for trial mixes

Type of material	C-25	C-50
Cement(kg)	305	530
Sand(kg)	965	850
Coarse aggregate(kg)	1025	920
Water(kg)	170	170

After the theoretical mix design, trial mixes were prepared and tested for compressive strength at 3 and 7 days. The results are shown in Table 4.4 and 4.5 below.

Table 4.4: Three and seven days‟ compressive strengths of trial mixes for C-25

Sample no	Test age (days)	Dimension [mm]			Weight [kg]	Failure load [kN]	Compressive strength [MPa]
		L	W	H			
1	3	150.15	151.8	152.24	7.2105	207.2	9.21
2	3	150.02	150.69	151.34	7.3545	204.5	9.09
3	3	150.06	151.82	153.34	7.3165	210.9	9.37
Mean						207.53	9.22
1	7	150.04	150.02	152.24	7.5035	291.6	12.96
2	7	150.27	150.6	150.83	7.454	281.7	12.52
3	7	151.79	150.28	152.58	7.5695	300.3	13.34
Mean						291.2	12.94

- Slump=48mm

Table 4.5: Three and seven days‟ compressive strengths of trial mixes for C-50

Sample no	Test age (days)	Dimension [mm]			Weight [kg]	Failure load [kN]	Compressive strength [MPa]
		L	W	H			
1	3	153.37	152.99	154.98	7.7040	561.5	24.95
2	3	150.09	150.14	151.84	7.3220	552.3	24.55
3	3	150.1	150.21	152.67	7.3740	546.3	24.28
Mean						553.37	24.59
1	7	150.27	150.09	152.9	7.554	787	34.98
2	7	150.03	150.87	150.12	7.498	752	33.42
3	7	150.18	150.23	151.14	7.426	754.8	33.54
Mean						764.6	33.98

* Slump=68mm

During trial mixing, the water used to keep the required workability was greater than the theoretical water content which affected the intended w/c ratios. The three day strengths of the trial mixes seem high enough to meet the required strength at 28 day; but the seven day strengths indicates the need of a certain adjustment to meet the design strength at 28 days. This reduction in strength is expected to be from w/c increment due to water increment to keep the mixes workable. Therefore the design was adopted keeping w/c or w/cm ratio and with adjustment of cement content in C-25 case and with addition of water reducing admixture in C-50 case. The adjusted mix proportion is shown below in Table 4.6.

Table 4.6: Proportion of materials after adjustment

Type of material	C-25	C-50
Cement(kg)	360	530
Sand(kg)	925	850
Coarse aggregate(kg)	980	920
Water(kg)	200	170
Admixture(lit)		9.17

4.3.3. Concrete Specimens Preparation

For studying the effects of replacing parts of cement and sand by marble waste powder, four groups of concrete specimens were prepared.

The first group designed for medium strength concrete(C-25) was prepared by replacing cement with marble waste powder from 0-20% replacement ranges with 5% increment to study the effects on performance of concrete.

Table 4.7: Proportion of materials for concrete specimens of group one, C-25

S.No	Code	Cement (kg)	Marble powder (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Water (kg)	Admixture (ml)	w/(cm)
1	CM0	21.6	0	58.8	55.5	12		0.56
2	CM5	20.52	1.08	58.8	55.5	12		0.56
3	CM10	19.44	2.16	58.8	55.5	12		0.56
4	CM15	18.36	3.24	58.8	55.5	12		0.56
5	CM20	17.28	4.32	58.8	55.5	12		0.56

The second group designed for high strength concrete(C-50) was prepared by replacing cement with marble waste powder from 0-20% replacement ranges with 5% increment to study the effects on performance of concrete.

Table 4.8: Proportion of materials for concrete specimens of group two, C-50

S.No	Code	Cement (kg)	Marble powder (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Water (kg)	Admixture (ml)	w/(cm)
1	CH0	31.8	0	55.2	51	10.2	550	0.34
2	CH5	30.21	1.59	55.2	51	10.2	550	0.34
3	CH10	28.62	3.18	55.2	51	10.2	550	0.34
4	CH15	27.03	4.77	55.2	51	10.2	550	0.34
5	CH20	25.44	6.36	55.2	51	10.2	550	0.34

The third group designed for medium strength concrete(C-25), was prepared by replacing sand with marble waste powder from 0-20% replacement ranges with 5% increment to study the effects on performance of concrete.

Table 4.9: Proportion of materials for concrete specimens of group three, C-25

S.No	Code	Cement (kg)	Marble powder (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Water (kg)	Admixture (ml)	w/(cm)
1	SM0	21.6	0	58.8	55.50	12		0.56
1	SM5	21.6	2.775	58.8	52.72	12		0.56
2	SM10	21.6	5.55	58.8	49.95	12		0.56
3	SM15	21.6	8.325	58.8	47.17	12		0.56
4	SM20	21.6	11.1	58.8	44.40	12		0.56

The forth group designed for high strength concrete(C-50), was prepared by replacing sand with marble waste powder from 0-20% replacement ranges with 5% increment to study the effects on performance of concrete.

Table 4.10: Proportion of materials for concrete specimens of group four, C-50

S.No	Code	Cement (kg)	Marble powder (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Water (kg)	Admixture (ml)	w/(cm)
1	SH0	31.8	0	55.2	51.0	10.2	550	0.34
2	SH5	31.8	2.55	55.2	48.45	10.2	550	0.34
3	SH10	31.8	5.1	55.2	45.9	10.2	550	0.34
4	SH15	31.8	7.65	55.2	43.35	10.2	550	0.34
5	SH20	31.8	10.2	55.2	40.8	10.2	550	0.34

For each mix code, 12 test cubes (15x15x15cm) and 3 test beams (50x10x10cm)] were prepared for compressive strength, water permeability and flexural strength tests.

Note: Description of the concrete specimen code is:

CM0=SM0 indicates control concrete specimen of C-25 prepared with Mossobo OPC without marble waste powder.

CH0=SH0 indicates control concrete specimen of C-50 prepared with Mossobo OPC without marble waste powder.

CM5 indicates concrete specimen of C-25 prepared with Mossobo OPC with 5% marble waste powder.

CM10 indicates concrete specimen of C-25 prepared with Mossobo OPC with 10% marble waste powder.

CM15 indicates concrete specimen of C-25 prepared with Mossobo OPC with 15% marble waste powder.

CM20 indicates concrete specimen of C-25 prepared with Mossobo OPC with 20% marble waste powder.

CH5 indicates concrete specimen of C-50 prepared with Mossobo OPC with 5% marble waste powder.

CH10 indicates concrete specimen of C-50 prepared with Mossobo OPC with 10% marble waste powder.

CH15 indicates concrete specimen of C-50 prepared with Mossobo OPC with 15% marble waste powder.

CH20 indicates concrete specimen of C-50 prepared with Mossobo OPC with 20% marble waste powder.

SM5 indicates concrete specimen of C-25 prepared with Mossobo OPC, and sand with 5% marble waste powder.

SM10 indicates concrete specimen of C-25 prepared with Mossobo OPC, and sand with 10% marble waste powder.

SM15 indicates concrete specimen of C-25 prepared with Mossobo OPC, and sand with 15% marble waste powder.

SM20 indicates concrete specimen of C-25 prepared with Mossobo OPC, and sand with 20% marble waste powder.

SH5 indicates concrete specimen of C-50 prepared with Mossobo OPC, and sand with 5% marble waste powder.

SH10 indicates concrete specimen of C-50 prepared with Mossobo OPC, and sand with 10% marble waste powder.

SH15 indicates concrete specimen of C-50 prepared with Mossobo OPC, and sand with 15% marble waste powder.

SH20 indicates concrete specimen of C-50 prepared with Mossobo OPC, and sand with 20% marble waste powder.

For each mix, mixing was done by first blending the powder homogenously to respective cement or sand. Then coarse aggregate, fine aggregate and cement was put to the mixer one over the other. These materials were mixed dry by vertical rotary mixer for about 1 minute. After dry mix, water was added. The wet mix was mixed for more than 2 minutes. During each mix slump test was taken.

After the mix was done, the fresh concrete was then poured in to the mould and compacted in two layers by vibration with vibrating table each layer for 15 seconds in cube mold cases, and for 15 seconds for first layer and 30 seconds for second layer in beam mold cases.

4.3.4. Curing

After the concrete was cast it was left for a time in open air .Then it was trimmed and, finished inside the mold .After finishing the specimens were left in the mold for 24 hours after which they were released from the mold and immersed in water pond for curing until test period.

CHAPTER FIVE

EXPERIMENTAL RESULTS AND DISCUSSIONS

5.1. Introduction

In this section the test results on the physical and chemical properties of marble waste powder blended cements (test results of experiment 1), the test results on the performance of concrete made with marble waste blended cement, and test results on the performance of concrete made with sand blended with marble waste powder (test results of experiment 2) are presented, analyzed and discussed.

5.2. Test Results and Discussions on Experiment One

In this part the test results on the physical and chemical properties of marble waste powder blended cements are presented, analyzed and discussed.

5.2.1. Suitability of Marble Waste Powder as Filler in Cement Production

To check the suitability of the marble waste powder as blending material in cement production, the research began by studying the physical and chemical properties of the powder.

As fineness affects filler effect, the fineness of the powder was taken as main evaluation criteria from physical properties. From chemical composition point, the calcium carbonate and clay content limit set by EN 197-1:2000 for Limestone Portland cement was taken as evaluation criteria.

Physically, as tested in the lab, the fineness values of the marble waste powder which was b/n 3571 and 4843 cm^2/kg are comparable with the fineness of modern Portland cement (3000-5000 cm^2/kg).Chemical composition analysis of all samples of marble waste powder, as shown in Table 3.4, showed that calcium carbonate contents were above 90%, clay contents were below 1.15gm/100gm and organic carbon contents were nil. These imply that the powders satisfy the three requirement limits set by EN 197-1 standard for Limestone Portland cement production. In addition other chemicals in the waste powder are very small in percentage.

From the EN 197-1 standard requirement of limestone (calcium carbonate) for Portland limestone cement production, the test results of the chemical composition of the marble waste powder, as shown in Table 3.4, ascertains the suitability of the waste powder for use as calcareous (calcium carbonate) filler in cement production.

5.2.2. Filler Effects of the Marble Waste Powder

To see the filler effects of the marble waste powder on the cement chosen for the test, the fineness of all marble waste powder blended cements were determined by Blaine air permeability apparatus and sieve. The test results are shown in Table 5.1 below.

Table 5.1: Fineness of marble waste powder blended cements

S.No	Code	By Blain (cm^2/kg)	By 63µm sieve (%)	By 90µm sieve (%)
1	MOPC	3113	9.3	2.3
2	MP5	3138	9.5	2.3
3	MP10	3218	9.4	2.3
4	MP15	3273	10.2	2.4
5	MP20	3234	11.7	2.4
6	MLP5	3202	10.6	2.0
7	MLP10	3281	11.0	2.3
8	MLP15	3227	11.1	2.4
9	MLP20	3484	11.3	2.4

From these tests, the increment of retained particles on sieving, with 63µm sieve, with increment of marble powder with the two fineness of the marble waste shows that the filler has certain percentage of grains coarser than the cement. The coarseness is greater in marble waste powder with fineness of 4843cm^2/kg than 3571cm^2/kg. Sieving on 90µm also ascertains the presence of more grains greater than size 90µm in the marble waste powder than in the cement. However the Blaine test shows an increment of Blaine with increment of percentage of powder in all cases except the interruption of the increment for 20% in case of marble waste powder with 3571cm^2/kg fineness. This in general implies that certain percentage of the marble waste powder grains are finer than certain grains of the cement. Therefore, for that particular fineness of the cement, the marble waste powder has filler effect on the cement. The filler effect is greater in marble powder with fineness of 4843cm^2/kg than with fineness of 3571cm^2/kg for the same percentage of addition.

5.2.3. Consistency of Cement Pastes

Normal consistency tests, for the blended cements, were conducted, by Vicat apparatus, to observe the changes in water requirement of pastes due to the marble waste powder filler.

Table 5.2: Normal consistency of marble waste powder blended cement pastes

S.No	Code	Consistency (%)
1	OPC	26
2	MP5	27
3	MP10	27
4	MP15	27
5	MP20	27
6	MLP5	27
7	MLP10	27
8	MLP15	27
9	MLP20	27

The majority of findings of researches on the effect of limestone on water requirement of OPC are in favor of lowering water requirement owning to suitable texture fineness and particle size distribution of cement containing limestone. However some find that the water reducing effect of limestone reduces with higher fineness of limestone [9].

The test results, as shown in Table 5.2, reveal a slight increase in water requirement for all cement with marble waste powder addition when compared to the control cement. This is attributed to the increment of fineness of blended cements. But the increment of the percentage of marble waste powder addition from 5 to 20% didn"t show remarkable change on the water requirement. The increment of fineness of marble waste powder from 3571 cm^2/kg to 4843 cm^2/kg also didn"t show change on the water requirement. This is probably due the interaction effects of water increment due to fineness of the powder and water requirement reduction effect due to accelerated hydration by the powder.

In all cases of blending, the normal consistencies of the pastes are within the range of the normal consistency for normal cement which is between 26-33% [14].

5.2.4. Setting Time

Tests for setting time were conducted to compare the setting time of the blended cements with standards and also with the control paste. The test results are shown in Table 5.3 below.

Table 5.3: Initial and final setting time of marble waste powder blended cement pastes

S.No	Code	Initial Setting time (minutes)	Final setting time (minutes)
1	OPC	93	163
2	MP5	84	149
3	MP10	90	153
4	MP15	92	150
5	MP20	102	162
6	MLP5	64	144
7	MLP10	86	150
8	MLP15	87	151
9	MLP20	72	148

The general consensus is that the fineness of limestone (calcium carbonate) is a factor influencing setting time of cement pastes. However, the magnitude of this effect differs among various studies [31].

For these particular finenesses of marble waste powder, the results show that the addition of marble waste powder has reduction effect on initial setting time up to 15% for marble waste powder with fineness of 3571cm^2/kg and up to 20% for marble waste powder with fineness of 4843cm^2/kg than the paste with cement of 0% marble waste powder addition. The addition of marble waste powder with these two finenesses also reduces final setting time compared to the paste with cement of 0% powder addition (the control). The reduction rate of both initial and final setting time with the addition of the powder increases as the fineness increases. The trend of reduction of both initial and final setting time with percentage increment of marble waste is not uniform.

This reduction in initial and final setting time is observed due to the powder‟s (calcium carbonate) action of forming nucleation sites for hydration products [31] which result in early hydration than the control paste.

EN 197-1:2000 limits the initial setting time for composite Portland cement not to be less than 45 minutes. The Ethiopian standard limits initial and final setting time for Portland pozzolana cement (ES C.D5.202, section 4.2.4) to be 45 minutes and 600 minutes respectively [29]. ASTM C 150 limits, for Vicant, setting time to be between 45 to 375 minutes [34].Comparing test results with standards, blended cements by addition of marble waste powder satisfy the requirement of European, ASTM and Ethiopian standards.

5.2.5. Soundness

When referring to Portland cement, "soundness" refers to the ability of a hardened cement paste to retain its volume after setting without delayed destructive expansion. This destructive expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO). Most Portland cement specifications limit magnesia content and expansion. ASTM C 150, Standard Specification for Portland cement specifies a maximum autoclave expansion of 0.80 percent for all Portland cement types [15]. According to the Ethiopian standard, the expansion of Portland cement shall not exceed 10mm [14].

In the research Le-Chatlier expansion tests were conducted for soundness test. The results are shown in Table 5.4 below.

Table 5.4: Soundness of marble waste powder blended cement pastes

S.no	Code	Soundness(expansion)
1	OPC	1mm
2	MP5	1mm
3	MP10	1mm
4	MP15	1mm
5	MP20	1mm
6	MLP5	1mm
7	MLP10	1mm
8	MLP15	1mm
9	MLP20	1mm

The expansion recorded is within the standard limits for Ordinary Portland cement set by ASTM and Ethiopian standard. The result revealed that the addition of marble waste powder on Ordinary Portland cement has no remarkable effects on the soundness of cement pastes.

During the investigation, sound produced by colliding dried pastes were observed and was uniform and thin light which indicates that there is no problem in expansion or no sign of cracking.

The absence of expansion in marble waste powder blended cement like the OPC cement reveals that the amount of free lime and MgO is controlled in clinkerization step and the free lime and MgO in the additive are little in quantity to affect late expansion.

5.2.6. Sulphur Trioxide (SO_3)

The sulphur Trioxide (SO_3) content in cement determines and affects late expansion due to delayed ettringite that standards put limits for it.

In this research, tests were conducted to see the effects of marble waste powder addition on OPC cement on sulphur trioxide.

Table 5.5: Loss on ignition, sulphate and insoluble residue of marble waste powder blended cements

S.No	Code	SO_3	I.R	LOI
1	OPC	3.14	1.21	1.05
2	MP5	3.01	1.19	2.84
3	MP10	2.84	2.62	5.22
4	MP15	2.63	1.29	7.46
5	MP20	2.5	1.58	8.89
6	MLP5	2.86	1.09	2.93
7	MLP10	2.99	1.14	5.22
8	MLP15	2.68	1.46	6.8
9	MLP20	2.57	0.97	8.9

From the results, as shown in Table 5.5 above, it is seen that the addition of marble waste powder reduces the percentage of SO_3 than the control OPC. The reduction percentage increases with increasing percentage of addition for both finenesses of the marble waste powder. This is due to the absence of SO_3 in the marble waste powder. Both the control cement and all the marble waste powder blended cements have SO_3 content below the upper limit of European standard requirement for composite Portland cement. The European standard requirement for lower strength class is expected to be less than 3.5 % and for higher strength classes is less than 4% [9].

Therefore both the control OPC and the blended cements are not expected to be affected by late expansion due to SO_3.Moreover, the marble waste powder blended cements have lesser percentage SO_3 „

5.2.7. Loss on Ignition (LOI)

High loss on ignition of cement indicates the extent of carbonation and prehydration of free lime and free magnesia which may be caused by improper and prolonged storage or adulteration during transport or transfer [11]. One of the reasons why cement standards limits LOI is that the loss represent organic content which is expected to hinder bond.

The total loss on ignition of the marble waste blended cements as shown in Table 5.5 increases with increment of addition of marble waste powder.This accounts to the conversion of $CaCO_3$ in to $CaO+CO_2$ which is intentionally added on the cement, and not related to pre-hydration as the cements are tested as soon as they are produced.

Therefore, the increment of LOI with the addition of the marble waste powder doesn"t have any negative meaning.

5.2.8. Insoluble Residue

Insoluble residue in cement contaminates clinker by materials other than calcium sulphate [38] that different standards limit insoluble residue content in cement.

In the research the effects of adding marble waste powder on insoluble residue was tested to check conformity with standards.

The results, as shown above in Table 5.5, show that the addition of the marble waste powder affects the insoluble residue (I.R) slightly with non uniform trend due to the presence of unreacted chemicals in the powder. However in all cases, it is below the standard set by EN 197-1 for composite cement. The specified requirement on European standard is expected to be less than or equal to 5% [9].

5.2.9. Compressive and Flexural Strength of Hardened Mortars

Different standards set minimum strength for different purpose cement as standard controlling parameters. In this research, mortars were prepared from Mugher OPC cement and marble waste powder blended cements in accordance with EN 196-1, Methods of testing cement, for examining the effects of the marble waste powder on the compressive and flexural strengths of mortars.

The compressive strength and flexural strengths of the mortars were tested on 2 and 28 days. The detail test results are given in the Appendices. But for discussion, the summarized and averaged test results are given in Table 5.6 below.

Table 5.6: Summarized and averaged compressive and flexural strengths of test mortars for two and twenty eight days.

S.No	Code	Average compressive strength				Average flexural strength			
		2 days		28 days		2 days		28 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	OPC	41.94	26.27	83.22	52.02	2.18	5.12	4.38	10.27
2	MP5	40.30	25.19	82.46	51.54	2.00	4.68	4.44	10.40
3	MP10	36.98	23.16	72.81	45.51	1.86	4.36	3.88	9.09
4	MP15	33.91	21.19	73.42	45.89	1.85	4.32	3.98	9.32
5	MP20	30.46	19.04	61.35	38.34	1.71	4.00	3.25	7.61
6	MLP5	40.41	25.27	79.69	49.81	2.02	4.74	4.21	9.86
7	MLP10	40.47	24.02	75.64	47.28	1.95	4.57	4.11	9.63
8	MLP15	35.48	22.16	72.25	45.15	1.88	4.40	3.90	9.17
9	MLP20	33.39	20.87	69.59	43.49	1.72	4.03	3.73	8.74

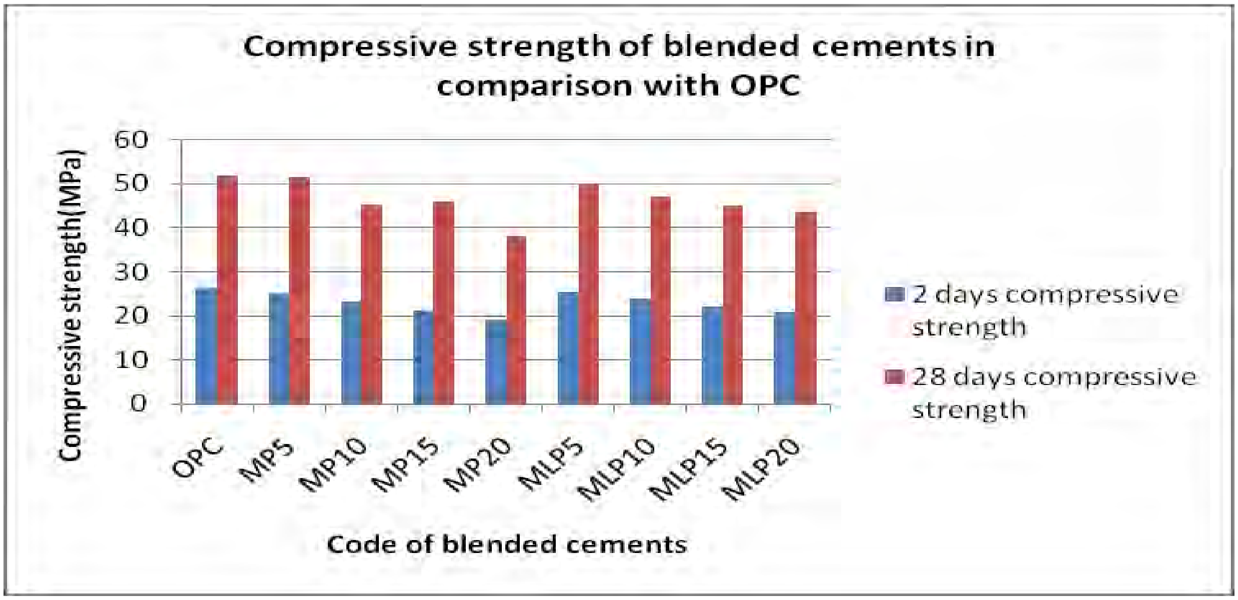

Fig.5.1: Comparison of compressive strength of blended cements with control OPC

Table 5.7: Strength deviation of marble waste powder blended cements

Code	**2 days compressive strength deviation from the control cement (%)**	**28 days compressive strength deviation from the control cement (%)**
MP5	4.11	0.92
MP10	11.84	12.51
MP15	19.34	11.78
MP20	27.52	26.29
`MLP5	3.8	4.25
MLP10	8.56	9.11
MLP15	15.64	13.21
MLP20	20.55	16.39

As shown in Table 5.7 above the degree of effects of the marble waste on two days compressive strengths are different. 5% additions of marble waste powder, with fineness of both $3571cm^2/kg$ and $4843cm^2/kg$, on OPC gave comparable strength as that of the control OPC cement at two days (only 4.11% and 3.8% compressive strength reduction was observed respectively).10% additions of marble waste powder, with fineness of both $3571cm^2/kg$ and $4843cm^2/kg$, on OPC resulted in a compressive strength reduction than the control (11.84% and 8.56% compressive strength reduction was observed respectively).15% additions of marble waste powder, with fineness of both $3571cm^2/kg$ and $4843cm^2/kg$, on OPC resulted in a compressive strength reduction than the control (19.34% and 15.64% compressive strength reduction was observed respectively).20 % additions of marble waste powder, with fineness of both $3571cm^2/kg$ and $4843cm^2/kg$, on OPC also resulted in a compressive strength reduction than the control (27.52% and 20.55% compressive strength reduction was observed respectively).

Similarly the test results on the 28^{th} days compressive strength showed effect in different degree.5% additions of marble waste powder, with fineness of both $3571cm^2/kg$ and $4843cm^2/kg$, on OPC gave comparable strength as that of the control one (only 0.92% and 4.25% compressive strength reduction was observed respectively).10% additions of marble waste powder, with fineness of both $3571cm^2/kg$ and $4843cm^2/kg$, on OPC resulted in strength reduction (12.51% and 9.11% respectively) than the control OPC.15% additions of marble waste powder, with fineness of both $3571cm^2/kg$ and $4843cm^2/kg$, on OPC, showed 11.78% and 13.21% compressive strength reduction than the control OPC respectively.20 % additions of marble waste powder, with fineness of both $3571cm^2/kg$ and $4843cm^2/kg$, on OPC also showed 26.29% and 16.39% compressive strength reduction than the control OPC respectively.

These all showed that the compressive and flexural strength of hardened cement mortars decreased with increase of powder content. These decreases in strength mainly occur due to replacement of Portland cement clinker with powder addition with different proportion causing dilution of C_3S and C_2S which is responsible for strength.

Comparing the effect of fineness of marble waste powder, generally, the finer marble waste shows less strength loss than the coarser one owing to its better filler effect.

However, EN 197-1 set, minimum compressive strength of hardened cement for high strength class of 32.5MPa, is equal to 10MPa for 2 days and 32.5MPa for 28 days and for a class of 42.5MPa the strength need to be greater or equal to 20MPa for 2 days and 42.5MPa for 28days.But the maximum strength for 28 days for this class should not be greater than 62.6MPa [9].

According to EN 197-1 the compressive strengths of the blended cements at two days satisfy EN 197-1 compressive strength limit for both classes of cement, in all cases except for 20 % addition of marble waste powder with 3571cm^2/kg fineness which doesn"t fulfill strength requirement of high early strength class 42.5MPa.

The 28th days compressive strengths of the blended cements also satisfy EN 197-1 compressive strength limit for both classes of cement in all cases except for 20 % addition of marble waste powder with 3571cm^2/kg fineness which doesn"t fulfill strength requirement of high early strength class 42.5MPa.

Therefore blending of marble waste powder with OPC at 5% with the indicated finenesses gives comparable strength to that of the control OPC. For 10 and 15 % blending ranges, though reduction in strength is observed, blended cements at these replacement ranges satisfy the European standard strength limits. At 20% blending range, compressive strengths are reduced considerably in both cases; however blended cements with marble powder of 4843cm^2/ kg fineness satisfies the European standard strength of class 42.5MPa, and blended cement with marble powder of 3571cm^2/kg fineness satisfies the European standard strength of class 32.5MPa.

5.2.10. Rate of Strength Development Comparison

The rate of strength development of cement which directly affects rate of development of concrete strength should be known for constructional technical purposes. Therefore, the rate of strength development of all samples of blended cements are calculated from 2 to 28 days and shown in Table 5.8 below.

Table 5.8: Rate of strength development of marble waste powder blended cements

S.No	Code	2 days compressive strength (MPa)	28 days compressive strength (MPa)	Rate of strength development (%)
1	OPC	25.92	52.02	200.69
2	MP5	25.19	51.54	204.60
3	MP10	23.16	45.51	196.50
4	MP15	21.19	45.89	216.56
5	MP20	19.04	38.84	203.99
6	MLP5	25.23	49.81	197.42
7	MLP10	25.34	47.28	186.58
8	MLP15	21.61	45.15	208.95
9	MLP20	20.87	43.53	208.57

The rate of strength development from 2 to 28 days is calculated and shown in Table 5.7 above. The trend of rate of development for both finenesses of marble waste powder is not uniform however for all cases the rate of strength development is comparable to the control OPC even in most cases with greater rate than OPC due to accelerated hydration rate as calcium carbonate act as nucleation site.

5.3. Test Results and Discussions on Experiment Two

In this part, the test results on performance of concretes made with marble waste blended cement, and test results on performance of concretes made with sand blended with marble waste powder are presented, analyzed and discussed.

5.3.1. Workability

Workability is affected by every component of concrete and essentially every condition under which concrete is made. A list of factors include the properties and the amount of cement, grading, shape, angularity and surface texture of fine and coarse aggregates, proportion of aggregates, amount of air entrained, type and amount of pozzolan, type and amount of chemical admixture, temperature of the concrete, mixing time and method, and time since water and cement are in contact. These factors interact so that changing the proportion of one component to produce a specific characteristic requires that other factors be adjusted to maintain workability [32].

Numerous attempts have been made by many research workers to quantitatively measure workability of concrete. But none of these methods are satisfactory for precisely measuring or expressing this property to bring out its full meaning [10].However many tests, measure parameters very close to workability and provide useful information.

In regards to the effect of limestone (calcium carbonate) additions on water demand and workability, there are conflicting results in the published literature. Much of these effects can be related to the particle size distribution of the limestone in relation to the cement. Generally, fine limestone particles can enhance the overall particle packing of the binder materials resulting in less space for water between the solid grains [31].

In this experiment slump of all mixes with constant water to cementious material (w/cm) ratio for the same group were measured to get information about workability changes due to the marble waste powder.

As it is shown below in Table 5.9, 5.10, 5.11 and 5.12, concrete mixes with cement substituted by marble waste powder show slump reduction than the control mix in both C-25 & C-50 cases. This is due to the reduction of the cement paste quantity as some part of the cement is replaced by the waste powder and as the particle size of the marble waste used was not much finer than the cement to enhance the particle packing density of the cement.

But in cases of sand substituted by marble waste powder, slump increment is observed with increment of marble waste powder in both C-25 & C-50 cases .This is due to the increment of the particle packing density of the sand due to the very fine filler which results in less space for water between the sand grains compared with the control mixes. The slump increment is greater in case of C-25 than the C-50 as the w/cm ratio in case of C-25 is greater than the C-50 one which emphasizes the cement paste to aggregate ratio than the C-50 one.

Table 5.9: Slump of class C-25 concrete specimens prepared with cement blended with marble waste powder

S.No	Mix code	Class	w/cm	Slump (mm)
1	CM0	C-25	0.56	56
2	CM5	C-25	0.56	46
3	CM10	C-25	0.56	47
4	CM15	C-25	0.56	28
5	CM20	C-25	0.56	28

Table 5.10: Slump of class C-50 concrete specimens prepared with cement blended with marble waste powder

S.No	Mix code	Class	w/cm	Slump (mm)
1	CH0	C-50	0.34	67
2	CH5	C-50	0.34	62
3	CH10	C-50	0.34	57
4	CH15	C-15	0.34	57
5	CH20	C-20	0.34	38

Table 5.11: Slump of class C-25 concrete specimens prepared with sand blended with marble waste powder

S.No	Mix code	Class	w/c	Slump (mm)
1	SM5	C-25	0.56	64
2	SM10	C-25	0.56	75
3	SM15	C-25	0.56	80
4	SM20	C-25	0.56	84

Table 5.12: Slump of class C-50 concrete specimens prepared with sand blended with marble waste powder

S.No	Code	Class	w/c	Slump (mm)
1	SH5	C-50	0.34	55
2	SH10	C-50	0.34	59
3	SH15	C-50	0.34	60
4	SH20	C-50	0.34	60

5.3.2. Compressive and Flexural Strength

For observing the performance changes due to the substitution of part of cement and sand by marble waste powder in concrete production ,two classes of concrete,C-25 and C-50, were prepared and tested for compressive strength at 2,7 and 28 days; and flexural strength at 28 days.

The test results for all samples are presented on the Appendices. But for the purpose of discussion the summarized test results are presented in Tables 5.13, 5.14, 5.15 and 5.16 below according to the type of the specimens.

5.3.2.1. Compressive and Flexural Strength of Concrete Specimens Prepared by Cement Blended with Marble Waste Powder

The strength of concrete is very much dependant up on the hydration reaction [16].The type and amount of cement used in concrete determines the hydration reaction.

The reactivity of calcium carbonate (limestone) has been debated while most researchers have previously believed that limestone serve as an inert filler, research shows that limestone does react to a limited extent.

Many research papers on influence of limestone ($CaCO_3$) powder on hydration of Portland cement have reported that the C_3S hydration rate is accelerated when the amount and fineness of

$CaCO_3$ is increased. This is due to the fact that they generate a large number of nucleation sites for precipitation of the hydration production.

The strength of concrete produced with limestone cement is strongly influenced by quality of limestone used, the manufacturing process (blending versus inter-grinding) and the final particle size distribution of the cement [31].

In this experiment, in all cases, i.e. for 5 to 20 % substitution of cement by marble waste powder for both C-25 and C-50 concrete specimens, the test results, as shown in Table 5.13 and 5.14 show that the third and seventh days compressive and flexural strengths of specimens with marble waste powder are less than that of the corresponding control specimens. The reduction of the strength increased with increasing percentage of marble waste powder.

These decreases in strength mainly occur due to replacement of Portland cement with powder addition causing dilution of C_3S and C_2S which is responsible for strength; and also due to less filler effect of the powder as the fineness of the waste powder being not much greater than that of the cement which probably hinders the $CaCO_3$ to be nucleation site.

The latter age strengths of concrete specimens at 28 days for 5% substitution for both C-25 and C-50 classes are almost the same as that of the corresponding control specimens. This is due to the filler effect of certain very fine particle of the marble powder in the mix which improves the particle packing of the cement that the strength reduction expected due to cement reduction is balanced by the improvement of particle packing of the cement. But beyond 5% substitution range for both C-25 and C-50 specimens, the 28 days strengths decreases with the addition of marble powder than the corresponding control specimens with reduction increment with the increment of percentage of marble waste powder; this attributes to the replacement of Portland cement by the powder which causes dilution of C_3S & C_2S which is responsible for strength and due to the inability of balancing the effect of strength reduction due cement reduction by improvement of particle packing of the cement due to the increment of coarser marble powder grains which couldn‟t be filled in between the cement particles.

For high strength concrete there is a theory that in low w/c ratio concrete some of the cement which couldn‟t be hydrated can be replaced by inert filler. In this experiment for medium high strength concrete a w/cm of 0.34 was used. For this w/cm ratio, only 5% substitution gave similar strength as the control mix .Here it is difficult to distinguish whether it is due to the effect of particle packing or due to the unhdration of cement in the control specimen.

Table 5.13: Averaged strengths of class C-25 concrete specimens prepared by cement blended with marble waste powder

S.No	Code	Average compressive strength						Average flexural strength
		3 days		7days		28days		28 days
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Strength (N/mm^2)
1	CM0	247.23	10.98	420.63	18.69	650.90	28.93	2.87
2	CM5	218.50	9.71	386.50	17.17	640.63	28.47	2.76
3	CM10	198.80	8.83	346.46	15.39	550.7	24.48	2.47
4	CM15	191.53	8.51	327.73	14.99	528.20	24.16	2.38
5	CM20	179.97	8.00	253.13	11.22	442.03	19.66	2.38

Table 5.14: Averaged strengths of class C-50 concrete specimens prepared by cement blended with marble waste powder

S.No	Code	Average compressive strength						Average flexural strength
		3 days		7days		28days		28 days
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Strength (N/mm^2)
1	CH0	608.84	26.93	847.93	37.68	1079.8	47.99	3.76
2	CH5	595.90	26.48	829.20	36.86	1095.30	48.67	3.63
3	CH10	516.53	22.95	732.87	32.57	978.90	43.50	3.13
4	CH15	503.50	22.38	703.10	31.25	934.10	41.51	3.31
5	CH20	465.83	20.70	693.10	30.80	905.5	40.16	3.50

5.3.2.2. Compressive and Flexural Strength of Concrete Specimens Prepared by Sand Blended with Marble Waste Powder

Conventional wisdom has held that micro fines have higher surface area that results in higher water demand. Higher water demand results in lower strength [18].But in aggregate, if instead of a single sized aggregate a multi-sized aggregate is used, the smaller size aggregate particles will fill up gaps between the larger size aggregate particles leading to a smaller volume of gaps within the aggregate skeleton. This firstly, the volume of cement paste needed to fill up the gaps within the aggregate skeleton will be reduced, secondly if the volume of cement is kept the same, the use of a multi-sized aggregate will increase the volume of excess paste which disperses the aggregate particles, provides a coating of paste for each aggregate particles and renders workability to the concrete mix [20].

In this experiment, the strength of concrete specimens, as shown in Table 5.15 & 5.16, with sand substituted by marble waste powder, for both C-25 & C-50 classes at 3, 7 and 28 days are the same as the corresponding control mix with most cases with a little degree strength enhancement by the addition of marble powder in all percentages than the corresponding control specimens. This is due to the improvement of particle packing density of the aggregate which increases the volume of excess paste which provides coating of paste for each aggregate. But there is no remarkable strength increment with percentage increment of marble powder in both C-25 and C-50 cases.

5.15: Averaged strengths of class C-25 concrete specimens prepared with sand blended with marble waste powder

S.No	Code	Average compressive strength						Average flexural strength
		3 days		7days		28days		28 days
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Strength (N/mm^2)
1	SM0	247.27	10.88	420.63	18.69	650.90	28.93	2.87
2	SM5	259.23	11.54	430.70	19.14	665.50	29.57	3.59
3	SM10	252.63	11.35	433.03	19.26	665.50	29.57	3.64
4	SM15	256.56	11.40	443.16	19.70	679.80	30.20	3.71
5	SM20	256.70	11.41	447.06	19.87	684.80	30.42	3.76

5.16: Averaged strengths of class C-50 concrete specimens prepared with sand blended with marble waste powder

S.No	Code	Average compressive strength						Average flexural strength
		3 days		7days		2 8days		28 days
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Strength (N/mm^2)
1	SH0	608.8	26.92	847.93	37.68	1079.80	47.99	3.76
2	SH5	617.93	27.46	926.43	40.93	1032.80	50.33	3.60
3	SH10	692.57	30.78	905.57	40.76	1051.60	51.19	3.86
4	SH15	688.00	30.57	914.80	40.65	1115.40	49.55	3.89
5	SH20	690.96	30.70	905.40	40.23	1099.80	49.31	3.94

5.3.3. Water Permeability

For assessing performance changes related with durability due to the addition of marble waste in cement and sand in concrete production, water permeability test, of non steady, was conducted.

This non steady state permeability was selected to be conducted because of the large sample number in this study and the long duration required to conduct steady state water permeability test on a sample .For instance, in one experimental study, manometer reading were taken everyday successively for 24 hours to eventually find out that the water flow has reached steady state after 7 days.

The test was conducted on normal concrete cubes of 150mm depth. The lower surface of the cubes were first scraped and polished to remove the troweled surface and to smoothen any irregularities present which may cause flow laterally. The cubes were then saturated in water before the test is started. Then the cubes were transferred to the permeability rig and assembled.

Due to time constraint only single sample was tested for a group .Thus three samples of different kind were tested simultaneously. Fig 5.2 shows the permeability apparatus with the test cubes assembled onto it. Once the setup was ready, water was filled in to the reservoir of the test cells and pressure was applied to specimen in succession described in section 2.3.1.3.1.1.2

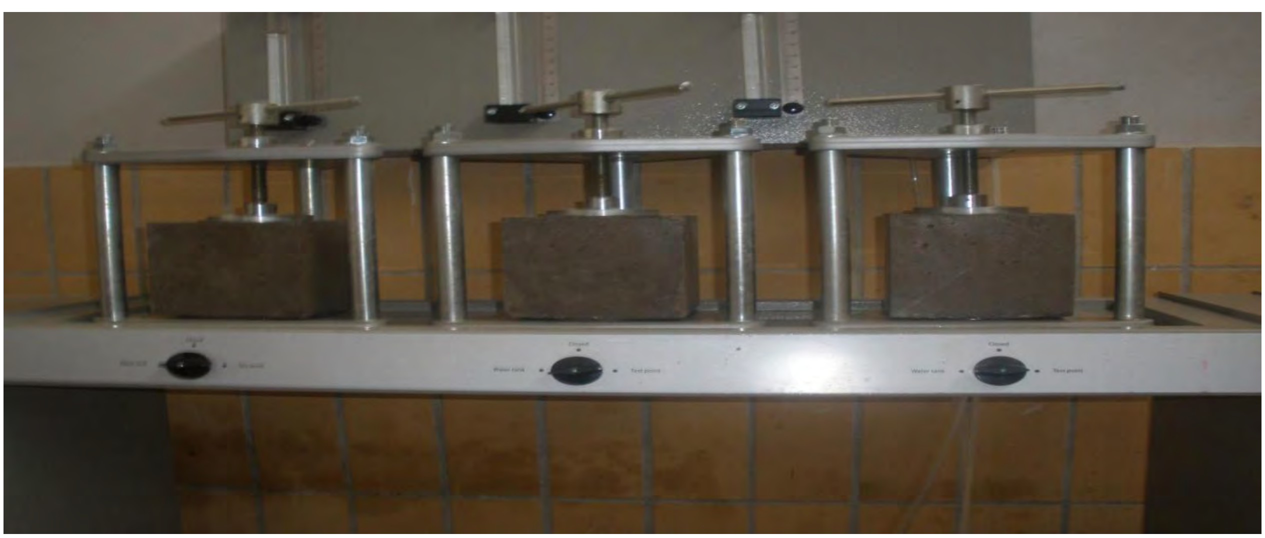

Fig 5.2: Permeability apparatus with the test cubes assembled on it

At the end of the 72 hour 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.

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 measured. To determine the average depth of penetration wit h more accuracy, measurements were taken at 30 mm intervals.

5.3.3.1. Water Permeability of Concrete Specimens Prepared by Cement Blended with Marble Waste Powder.

The detail test results are given on Appendix M. But for discussion, the average and maximum depth of water penetration depths are shown below in Table 5.17.

Table 5.17: Water penetration depth of concrete specimens at 40 days age

Sample no	Code	Concrete class	Penetrated depth(mm)	
			Average	maximum
1	CM0	C-25	22.4	30
2	CM5	C-25	22.8	29
3	CM10	C-25	24	27
4	CM15	C-25	19.4	28
5	CM20	C-25	20.4	28
6	CH0	C-50	5.2	9
7	CH5	C-50	3.6	5
8	CH10	C-50	5.6	10
9	CH15	C-50	8	11
10	CH20	C-50	10	13
11	SM0	C-25	22.4	30
12	SM5	C-25	10	12
13	SM10	C-25	8.6	12
14	SM15	C-25	8.0	12
15	SM20	C-25	8.6	11

16	SH0	C-50	5.2	9
17	SH5	C-50	5.4	8
18	SH10	C-50	5.2	8
19	SH15	C-50	4.6	7
20	SH20	C-50	4	5

The permeability tests at 40 days age for concrete specimens of class C-25 case, with cement substituted by marble waste powder, don"t show much significance changes from the control specimen and among one another; the changes are not also uniform for both the average and maximum depth of penetration probably due to the early age of test taken due to time constraint for the thesis. However, the test results generally show that all specimens with cement substituted by marble powder have no much significant depth increment than the control one; rather water penetration depth reductions are recorded in most cases.

But in case of class C-50 specimens, water penetration depth increments are recorded with substitution of the cement with marble waste powder except for 5% replacement range. This is due to the reduction of cement amount that reduces the CHS(calcium hydro silicate) part which was responsible for reducing gel pores .The exception for the 5% replacement range is may be due to the filling effects of certain micro size particles of the marble powder which makes the paste more compact.

5.3.3.2. Water Permeability of Concrete Specimens Prepared by Sand Blended with Marble Waste Powder.

In case of sand substitution, the changes of water penetration depths, in both C-25 and C-50 classes, are not also uniform probably due to the early age of test. But generally in all specimens with marble powder, water penetration depth reduction is recorded than the corresponding control specimen. This is due to the filler effects of the powder in the gaps between the sand particles which gives compacted mortar paste than the mortar paste in the corresponding control specimen.

Comparing the C-50 and C-25 classes, in both the cement and sand substitution cases, all the C-50 class samples show lower water penetration depth than all class C-25 samples attributed to low w/cm ratio.

Comparing the cement substitution case with that of sand substitution case correspondingly(C-50 with C-50 & C-25 with C-25) ,the sand replacement show lower water depth penetration than the cement replacement case attributed to the better filler effect of the powder between the sand particles than between the cement particles which results in more dense mortar paste.

CHAPTER SIX

ECONOMICAL AND ENVIRONMENTAL ANALYSIS

6.1. Introduction

Recycling of industrial wastes has actually environmental, economical and technical benefits. These benefits can be seen from two different angles, one from the point of the waste producer and the other from the user part.

For the producer, the benefits of recycling industrial wastes are economical and environmental; for the user additional technical benefits may be attained from recycling.

For the producer, the environmental benefit can be attained as far as the waste is recycled. It is independent of where it is recycled. But the economical benefit is determined on the demand for the waste by different users. The more users, the more demand will be; there by more economical benefit to the producer.

With respect to the user, recycling of industrial wastes will be environmentally beneficial as far as using the waste reduces waste emitted during production of similar product from other raw alternative materials. The economical benefit is assured if the cost of the waste material is cheaper than other alternative raw materials. The technical benefit is also attained if the recycled input improves the quality of the output than the output from other alternative material. Therefore it is necessary to see recycling of marble waste powder with respect to both the producer and the user part.

6.2. For the Marble Waste Powder Producer

As it is mentioned in part 6.1, the producer of a waste will ensure environmental benefits as far as the waste is recycled. It is also expected that it can get more economical benefits when there is more demand for the waste.

Therefore, the use of marble waste in the construction industry undoubtedly will increase the demand for the waste thereby benefits the producer both environmentally and economically.

6.3. For the Construction Industry

6.3.1. Environmental Benefits

One of the greatest environmental concerns in construction industry is the production of cement which emits large amount of CO_2 gas to the atmosphere. It is estimated that 1 tone clinker production releases 1 tone CO_2 [35].Mixing of clinker to supplementary materials called blending is considered as a very effective way to reduce CO_2 emission [42].

It is estimated that The Ethiopian Marble Processing Enterprise produces 1800m^3 (4500 tons) marble waste annually, which implies that using marble waste of The Ethiopian Marble Processing Enterprise as cement replacing material can indirectly reduce CO_2 emission to the atmosphere by 4500 tons annually.

Recycling marble waste powder in substitution of sand also indirectly can reduce environmental problem related with sand production.

6.3.2 Economical Benefits

In this research work, detail cost break down and economical analysis was not worked out as the cost of cement and sand depends on its user point location and also due to lack of necessary data and required information; but to give insight for cost benefits, the average cost of cement, sand and selling price of marble waste is presented below in Table 6.1.

Table 6.1: Average price of cement, sand and marble waste in Addis Ababa

S.No	Type of Material	Average Price (Birr)
1	Cement	250 per quintal
2	Sand	220 per m^3
3	Marble waste	9 per quintal

The above figures clearly show that using of marble waste in replacement of cement or sand in Addis Ababa can play cost reduction in concrete production.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

Construction industry by itself is a great concern related to environmental pollution and also related to degradation of environment due to consumptions of large amount of non renewable natural resources.

Recycling of industrial wastes is one of the solutions given attention worldwide for environmental protection and for economical and sustainable use of resources.

In this research, recycling of marble waste powder for the production of cement and concrete has been studied and the following conclusions are made.

1. Marble waste powder from The Ethiopian Marble Processing Enterprise used for the study satisfies the chemical standard requirement of EN 197-1 for production of Portland limestone cement; and natural fineness of the marble waste is comparable with that of the fineness of modern cements to be used as filler.
2. Replacement of Ordinary Portland cement by marble waste powder at 5% replacement range gives comparable compressive strength with that of 100% ordinary Portland cement. Replacement at 10%, 15% and 20% replacement ranges result in compressive strength reduction than that of 100% Ordinary Portland cement. However blended cements with 5 to 15% replacement ranges satisfy the standard of high early strength of class 42.5MPa and blended cements at 20% replacement range satisfy the standard of high early strength of class 32.5MPa as per the EN 197-1 standard.
3. Increasing percentage of addition of marble waste to Ordinary Portland cement results in general compressive strength reduction than OPC. But other properties of marble waste blended cements such as consistency, setting times, insoluble residue, sulphate residue and soundness remain within the acceptable limits of different standards.

4. The investigation revealed that replacing of cement with marble waste powder up to 20 % reduces the slump of concrete mixes; whereas replacement of sand by marble waste powder up to 20% enhances the slump of the concrete mixes.
5. In concrete production replacement of 5% cement by marble waste powder gives comparable compressive and flexural strength as of marble waste free concrete specimens; but increasing the replacement range beyond 5% results in strength reduction.
6. 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.
7. The replacement of 5% cement by marble waste powder reduces water penetration depth in concrete specimens; but increasing the replacement range beyond 5% increases water penetration depth of concrete specimens.
8. The replacement of sand up 20% by marble waste powder reduces water penetration depth of concrete specimens.
9. The study indicates that the marble waste can be incorporated in Portland limestone production.
10. The study indicates that the marble waste up to 20% can replace sand with performance improvement of concrete strength and durability related with water permeability.

7.2. Recommendations

Each region of the world should play role in environmental protection and sustainable use of natural resources. Ethiopian construction industries also need to benefit from recycling of wastes as other countries did.

Therefore based on the study the following recommendations are forwarded.

1. Marble waste from The Ethiopian Marble Processing Enterprise can substitute part of sand in concrete production; But the current disposal methods of the waste by the enterprise is not comfortable for using it. Therefore the Ethiopia Marble Enterprise should undergo investigation how and where to dispose it in such a way that it will be easy for accessing the waste.
2. Marble waste from The Ethiopian Marble Processing Enterprise can be used in Portland Limestone cement production and as 5% calcareous filler in OPC cement. But currently there is no cement factory which is near to the marble processing factory which makes using this by product non feasible cost wise. However in near future Mugher will complete its expansion factory which is 25km away from The Marble Processing Factory. This distance is shorter compared to Mugher"s raw material quarry which is 100km far. Therefore the Enterprise should work with Mugher factory for further study and applications.
3. Currently in Ethiopia cement is delivered to the consumers in cement bags, but in future if cement delivery to the consumers begin in bulk, the marble waste powder can be one alternative material to be used as cement blending material to be directly applied by the consumer as their requirements.
4. In this research, only some basic study of using marble waste in cement and concrete production is investigated; therefore, further investigations are required on the following areas.
    - Studies should be made by grinding marble waste powder together with cement using different fineness and types of cements and with more percentage of marble waste replacement.
    - Detail study of durability of concrete made by marble waste blended cement or sand should be made.

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APPENDIX-A

Test Results of Compressive Strength of Marble Waste Blended Cements

Mix code	Specimen No	Casting date	Dimensions of prism (mm)			Test result at two days		Test result at twenty eight days	
			L	W	H	Failure load(kN)	Compressive strength(MPa)	Failure load(kN)	Compressive strength(MPa)
MOPC	1	11/07/10	160	40	40	39.92	24.95	82.20	51.31
	2	11/07/10	160	40	40	42.69	26.68	82.77	51.73
	3	11/07/10	160	40	40	40.63	25.39	81.58	50.99
	4	11/07/10	160	40	40	43.30	27.42	83.41	52.13
	5	11/07/10	160	40	40	40.42	25.15	83.55	52.22
	6	11/07/10	160	40	40	44.87	28.05	85.94	53.71
Average result						**41.97**	**26.27**	**83.24**	**52.02**
MP5	1	11/07/10	160	40	40	38.72	24.20	82.98	51.86
	2	11/07/10	160	40	40	40.49	25.31	80.35	50.22
	3	11/07/10	160	40	40	40.02	25.01	84.37	52.73
	4	11/07/10	160	40	40	41.23	25.77	79.78	49.86
	5	11/07/10	160	40	40	41.31	25.82	83.30	52.06
	6	11/07/10	160	40	40	40.01	25.01	84.02	52.51
Average result						**40.30**	**25.19**	**82.47**	**51.54**
MP10	1	11/07/10	160	40	40	34.57	21.61	74.48	46.55
	2	11/07/10	160	40	40	37.95	23.72	76.40	47.75
	3	11/07/10	160	40	40	36.24	22.65	73.49	45.93
	4	11/07/10	160	40	40	37.33	23.33	76.86	48.04
	5	11/07/10	160	40	40	37.58	23.49	68.94	43.09
	6	11/07/10	160	40	40	38.18	24.18	70.34	43.96
Average result						**36.98**	**23.16**	**73.42**	**45.89**

MP15	1	11/07/10	160	40	40	34.06	21.29	73.62	46.01
	2	11/07/10	160	40	40	32.15	20.09	75.14	46.96
	3	11/07/10	160	40	40	33.65	21.03	72.19	45.12
	4	11/07/10	160	40	40	33.00	20.59	71.49	44.68
	5	11/07/10	160	40	40	36.14	22.59	72.69	45.43
	6	11/07/10	160	40	40	34.45	21.53	71.76	44.85
Average result						**33.90**	**21.19**	**72.82**	**45.51**
MP20	1	14/07/10	160	40	40	30.45	19.03	48.72	37.48
	2	14/07/10	160	40	40	29.06	18.16	59.58	37.24
	3	14/07/10	160	40	40	30.52	19.08	62.53	39.08
	4	14/07/10	160	40	40	32.03	20.02	62.00	38.75
	5	14/07/10	160	40	40	30.15	18.84	61.87	38.67
	6	14/07/10	160	40	40	30.55	19.10	62.14	38.84
Average result						**30.46**	**19.04**	**59.47**	**38.34**
MLP5	1	12/07/10	160	40	40	40.61	25.38	73.60	46.00
	2	12/07/10	160	40	40	40.95	25.59	76.88	48.05
	3	12/07/10	160	40	40	40.65	25.41	81.95	51.22
	4	12/07/10	160	40	40	41.20	25.75	82.85	51.78
	5	12/07/10	160	40	40	41.41	25.88	81.65	51.03
	6	12/07/10	160	40	40	38.02	24.02	81.22	50.76
Average result						**40.47**	**25.34**	**79.69**	**49.81**
MLP10	1	12/07/10	160	40	40	39.43	24.65	75.09	46.93
	2	12/07/10	160	40	40	40.20	25.12	76.72	47.95
	3	12/07/10	160	40	40	40.98	25.61	78.21	48.88
	4	12/07/10	160	40	40	40.24	25.24	72.05	45.03
	5	12/07/10	160	40	40	40.82	25.51	78.21	48.88
	6	12/07/10	160	40	40	40.79	25.49	73.57	45.98
Average result						**40.41**	**25.27**	**75.64**	**47.28**

MLP15	1	12/07/10	160	40	40	35.12	21.95	75.17	46.98
	2	12/07/10	160	40	40	35.47	22.17	69.57	43.48
	3	12/07/10	160	40	40	35.10	21.90	73.42	45.89
	4	12/07/10	160	40	40	35.42	22.14	71.22	44.51
	5	12/07/10	160	40	40	37.17	23.23	72.45	45.28
	6	12/07/10	160	40	40	34.57	21.61	71.65	44.78
Average result						**35.48**	**22.17**	**72.25**	**45.15**
MLP20	1	12/07/10	160	40	40	33.29	20.81	70.14	43.84
	2	12/07/10	160	40	40	33.09	20.68	66.27	41.42
	3	12/07/10	160	40	40	32.47	20.29	71.44	44.65
	4	12/07/10	160	40	40	33.82	21.14	71.02	44.39
	5	12/07/10	160	40	40	34.01	21.26	69.41	43.38
	6	12/07/10	160	40	40	33.63	21.02	69.25	43.28
Average result						**33.39**	**20.87**	**69.59**	**43.49**

APPENDIX-B

Test Results of Flexural Strength of Marble Waste Blended Cements

Mix code	Specimen No	Casting date	Dimensions of prism (mm)			Test result at Two days		Test result at Twenty eight days	
			L	W	H	Failure load(kN)	Flexural strength(MPa)	Failure load(kN)	Flexural strength(MPa)
MOPC	1	11/07/10	160	40	40	2.16	5.07	3.59	8.41
	2	11/07/10	160	40	40	2.23	5.24	3.5	8.70
	3	11/07/10	160	40	40	2.16	5.05	3.5	8.80
Average result						**2.18**	**5.12**	**3.53**	**8.64**
MP5	1	11/07/10	160	40	40	1.90	4.45	3.15	7.37
	2	11/07/10	160	40	40	2.12	4.97	3.6	8.20
	3	11/07/10	160	40	40	1.97	4.62	3.21	7.65
Average result						**1.99**	**4.68**	**3.32**	**7.74**
MP10	1	11/07/10	160	40	40	1.94	4.56	3.22	7.55
	2	11/07/10	160	40	40	1.84	4.31	3.00	7.30
	3	11/07/10	160	40	40	1.80	4.22	3.00	7.00
Average result						**1.86**	**4.36**	**3.07**	**7.28**
MP15	1	11/07/10	160	40	40	1.94	4.55	3.21	7.51
	2	11/07/10	160	40	40	1.73	4.06	2.88	6.74
	3	11/07/10	160	40	40	1.86	4.36	3.00	7.24
Average result						**1.84**	**4.32**	**3.03**	**7.16**
MP20	1	14/07/10	160	40	40	1.62	3.80	2.59	6.3
	2	14/07/10	160	40	40	1.79	4.17	3.02	6.7
	3	14/07/10	160	40	40	1.73	4.04	2.87	6.47
Average result						**1.71**	**4.00**	**2.83**	**6.49**

MLP5	1	12/07/10	160	40	40	2.07	4.86	3.44	8.06
	2	12/07/10	160	40	40	2.07	4.84	3.51	7.98
	3	12/07/10	160	40	40	1.93	4.51	3.01	7.34
Average result						**2.02**	**4.74**	**3.32**	**7.79**
MLP10	1	12/07/10	160	40	40	1.91	4.47	3.16	7.41
	2	12/07/10	160	40	40	2.02	4.74	3.33	7.96
	3	12/07/10	160	40	40	1.92	4.51	3.23	7.58
Average result						**1.95**	**4.57**	**3.24**	**7.65**
MLP15	1	12/07/10	160	40	40	1.83	4.28	3.07	7.23
	2	12/07/10	160	40	40	1.93	4.53	3.16	7.46
	3	12/07/10	160	40	40	1.88	4.40	3.18	7.36
Average result						**1.88**	**4.40**	**3.14**	**7.35**
MLP20	1	12/07/10	160	40	40	1.73	4.06	2.83	6.33
	2	12/07/10	160	40	40	1.79	4.21	2.97	7.12
	3	12/07/10	160	40	40	1.63	3.82	2.69	6.45
Average result						**1.72**	**4.03**	**2.82**	**6.63**

APPENDIX-C

Three Days Compressive Strength of Concrete Specimens Prepared By Cement Blended With Marble Waste Powder

Mix code	Specimen No	Casting date	Dimensions of prism (mm)			Weight (g)	Test result at three days	
			L	W	H		Failure load(kN)	Compressive strength(MPa)
CM0	1	15/09/10	150.0	150.0	150.2	7563.5	236.6	10.52
	2	15/09/10	150.0	150.1	150.0	7506.5	248.8	11.06
	3	15/09/10	150.2	150.2	152.3	7952.5	256.3	11.06
Average result							**247.23**	**10.88**
CM5	1	15/09/10	150.0	150.0	150.2	7459.0	201.4	8.95
	2	15/09/10	150.2	150.6	150.4	8060.0	234.1	10.40
	3	15/09/10	150.0	150.2	150.0	7463.0	220.0	9.80
Average result							**218.5**	**9.71**
CM10	1	17/09/10	150.1	150.0	149.0	7570.5	206.1	9.16
	2	17/09/10	149.0	150.0	150.0	7293.5	196.4	8.73
	3	17/09/10	150.0	150.1	150.0	7358.0	194.0	8.62
Average result							**198.8**	**8.83**
CM15	1	17/09/10	150.2	150.5	153.0	7535.5	192.6	8.56
	2	17/09/10	150.0	150.0	150.2	7386.5	190.4	8.46
	3	17/09/10	150.0	150.1	148.0	7307.5	191.6	8.52
Average result							**191.53**	**8.51**
CM20	1	20/09/10	150.0	150.1	150.0	7253.0	189.6	8.43
	2	20/09/10	150.0	150.0	150.0	7239.0	176.0	7.82
	3	20/09/10	150.0	150.0	150.1	7252.0	174.3	7.75
Average result							**179.9**	**8.00**

CH0	1	21/09/10	150.0	150.0	150.0	7452.0	600.9	26.31
	2	21/09/10	151.0	150.0	150.0	7469.0	614.9	27.33
	3	21/09/10	151.0	150.0	150.2	7311.0	610.7	27.14
Average result							**608.8**	**26.93**
CH5	1	21/09/10	150.0	150.2	150.0	7437.0	601.6	26.72
	2	21/09/10	151.0	150.0	150.0	7490.0	584.0	25.95
	3	21/09/10	151.0	150.0	150.2	7363.0	602.1	26.76
Average result							**595.9**	**26.48**
CH10	1	23/09/10	150.0	150.0	150.0	7330.0	517.90	23.01
	2	23/09/10	149.0	150.0	150.2	7482.0	506.30	22.50
	3	23/09/10	150.0	150.0	150.0	7255.0	525.40	23.35
Average result							**516.53**	**22.95**
CH15	1	22/09/10	150.0	150.0	150.0	7436.0	514.3	22.86
	2	22/09/10	150.0	150.0	150.2	7489.0	500.9	22.26
	3	22/09/10	150.0	150.0	150.0	7599.0	495.3	22.01
Average result							**503.5**	**22.38**
CH20	1	22/09/10	150.0	150.0	150.0	7475.0	485.1	21.56
	2	22/09/10	150.0	150.0	150.2	7608.0	428.8	19.06
	3	22/09/10	150.0	150.0	150.0	7476.0	483.6	21.49
Average result							**465.83**	**20.70**

APPENDIX-D

Seven Days Compressive Strength of Concrete Specimens Prepared By Cement Blended With Marble Waste Powder

Mix code	Specimen No	Casting date	Dimensions of prism (mm)			Weight (g)	Test result at seven days	
			L	W	H		Failure load(kN)	Compressive strength(MPa)
CM0	1	15/09/10	150.0	150.1	150.2	7492.0	427.2	18.98
	2	15/09/10	150.0	150.0	150.0	7473.0	418.6	18.60
	3	15/09/10	150.0	150.2	152.3	7467.0	416.1	18.49
Average result							**420.63**	**18.69**
CM5	1	15/09/10	150.0	150.1	150.2	7502.0	383.4	17.04
	2	15/09/10	150.0	150.0	150.0	7314.0	388.8	17.28
	3	15/09/10	150.0	150.1	150.1	7456.0	387.3	17.21
Average result							**386.5**	**17.17**
CM10	1	17/09/10	150.1	150.1	150.0	7269.0	351.4	15.61
	2	17/09/10	150.0	150.2	150.0	7470.0	346.0	15.38
	3	17/09/10	150.3	150.4	150.4	7895.0	342.0	15.20
Average result							**346.4**	**15.39**
CM15	1	17/09/10	150.0	150.1	150.0	7410.0	306.7	13.63
	2	17/09/10	150.0	150.1	150.0	7265.0	339.1	15.07
	3	17/09/10	150.0	150.2	150.0	7347.0	337.4	14.99
Average result							**327.7**	**4.56**
CM20	1	20/09/10	150.0	150.0	150.2	7361.0	262.0	11.62
	2	20/09/10	150.0	150.0	150.0	7251.0	246.3	10.95
	3	20/09/10	150.0	150.0	150.0	7349.0	251.1	11.11
Average result							**253.1**	**11.22**

CH0	1	21/09/10	150.0	150.0	150.2	7438.0	853.8	37.95
	2	21/09/10	150.0	150.0	150.2	7411.0	834.2	37.07
	3	21/09/10	150.0	150.0	150.2	7518.0	855.8	38.03
Average result							**847.9**	**37.68**
CH5	1	21/09/10	150.3	150.2	150.3	7956.0	869.10	38.63
	2	21/09/10	150.0	150.0	150.2	7541.0	814.50	36.20
	3	21/09/10	150.0	150.1	150.1	7597.0	804.0	35.74
Average result							**829.2**	**36.85**
CH10	1	23/09/10	150.0	150.0	150.2	7437.0	806.10	35.83
	2	23/09/10	150.0	150.3	150.3	7538.0	636.4	28.28
	3	23/09/10	150.3	150.0	150.0	7510.0	756.10	33.60
Average result							**732.87**	**32.57**
CH15	1	22/09/10	150.0	150.1	150.0	8040.0	687.9	30.57
	2	22/09/10	150.0	150.0	150.2	7530.0	719.2	31.97
	3	22/09/10	150.0	150.0	150.2	7516.0	702.2	31.21
Average result							**703.1**	**31.25**
CH20	1	22/09/10	150.0	150.0	150.0	7479.0	733.6	32.60
	2	22/09/10	150.0	150.0	150.0	7657.0	719.4	31.97
	3	22/09/10	150.0	150.0	150.0	7599.0	626.3	27.84
Average result							**465.83**	**30.80**

APPENDIX-E

Twenty Eight Days Compressive Strength of Concrete Specimens Prepared By Cement Blended With Marble Waste Powder

Mix code	Specimen No	Casting date	Dimensions of prism (mm)			Weight (g)	Test result at twenty eight days	
			L	W	H		Failure load(kN)	Compressive strength(MPa)
CM0	1	15/09/10	150.0	150.2	150.0	7463.0	635.7	28.25
	2	15/09/10	150.0	150.2	150.0	7375.0	680.4	30.24
	3	15/09/10	150.0	150.2	152.0	7952.0	636.7	28.30
Average result							**650.9**	**28.93**
CM5	1	15/09/10	150.0	150.1	150.3	7369.0	637.6	28.34
	2	15/09/10	150.3	150.3	150.4	7867.0	629.3	27.97
	3	15/09/10	150.0	150.2	150.2	7437.0	655.0	29.11
Average result							**640.6**	**28.47**
CM10	1	17/09/10	150.3	150.3	150.4	7771.0	546.7	24.30
	2	17/09/10	150.0	150.0	150.3	7333.0	531.5	23.62
	3	17/09/10	150.0	150.0	150.3	7435.0	573.9	25.51
Average result							**550.7**	**24.48**
CM15	1	17/09/10	150.0	150.0	150.2	7325.0	543.5	24.15
	2	17/09/10	150.0	150.1	150.2	7436.0	540.1	24.00
	3	17/09/10	150.0	150.0	150.2	7302.0	547.6	24.34
Average result							**543.7**	**24.16**
CM20	1	20/09/10	150.0	150.0	150.1	7356.0	437.1	19.43
	2	20/09/10	150.1	150.0	150.1	7251.0	447.0	19.87
	3	20/09/10	150.2	150.1	150.0	7400.0	442.9	19.68
Average result							**442.0**	**19.66**

CH0	1	21/09/10	150.0	150.0	150.2	7427.0	1123.8	49.95
	2	21/09/10	150.2	150.0	150.1	7439.0	1139.8	50.65
	3	21/09/10	150.2	150.0	150.2	7509.0	976.0	43.38
Average result							**1079.8**	**47.99**
CH5	1	21/09/10	150.0	150.0	151.0	7479.0	1097.2	48.76
	2	21/09/10	150.0	150.0	152.0	7558.0	1085.6	48.24
	3	21/09/10	150.0	150.0	151.0	7441.0	1103.1	49.02
Average result							**1095.3**	**48.67**
CH10	1	23/09/10	150.0	150.0	150.1	7575.0	1015.0	45.11
	2	23/09/10	150.0	150.2	150.2	7660.0	878.0	39.02
	3	23/09/10	150.3	150.0	150.1	7568.0	1043.7	46.39
Average result							**978.9**	**43.5**
CH15	1	22/09/10	150.0	150.0	150.2	7356.0	969.9	43.10
	2	22/09/10	150.3	150.1	150.1	7251.0	860.9	38.26
	3	22/09/10	150.0	150.0	150.0	7400.0	971.5	43.17
Average result							**934.1**	**41.51**
CH20	1	22/09/10	150.0	150.0	150.3	7470.0	960.7	42.45
	2	22/09/10	150.0	150.0	150.2	7515.0	925.7	41.14
	3	22/09/10	150.0	150.1	150.2	7502.0	830.3	36.90
Average result							**905.5**	**40.16**

APPENDIX-F

Three Days Compressive Strength of Concrete Specimens Prepared By Sand Blended With Marble Waste Powder

Mix code	Specimen No	Casting date	Dimensions of prism (mm)			Weight (g)	Test result at three days	
			L	W	H		Failure load(kN)	Compressive strength(MPa)
SM0	1	15/09/10	150.0	150.0	150.2	7563.5	236.6	10.52
	2	15/09/10	150.0	150.1	150.0	7506.5	248.8	11.06
	3	15/09/10	150.2	150.2	150.2	7952.5	256.3	11.06
Average result							**247.2**	**10.88**
SM5	1	28/09/10	150.0	150.0	150.0	7552.0	258.7	11.50
	2	28/09/10	150.0	150.0	150.0	7852.0	250.9	11.50
	3	28/09/10	150.0	150.0	150.0	7367.0	248.3	11.04
Average result							**259.23**	**11.54**
SM10	1	29/09/10	150.0	150.0	150.0	7552.0	258.7	11.50
	2	29/09/10	150.0	150.0	150.0	7852.0	250.9	11.50
	3	29/09/10	150.0	150.0	150.0	7367.0	248.3	11.04
Average result							**252.63**	**11.35**
SM15	1	30/09/10	150.0	150.1	150.1	7429.0	256.0	11.37
	2	30/09/10	150.0	150.0	150.0	7290.0	255.4	11.35
	3	30/09/10	150.0	149.0	150.2	7357.0	258.3	11.48
Average result							**256.5**	**11.40**
SM20	1	30/09/10	149.0	150.0	149.0	7484.0	254.0	11.29
	2	30/09/10	149.0	150.0	150.0	7436.0	255.8	11.37
	3	30/09/10	150.0	150.0	149.0	7480.0	260.3	11.57
Average result							**256.7**	**11.41**

SH0	1	21/09/10	150.0	150.0	150.0	7452.0	600.9	26.31
	2	21/09/10	151.0	150.0	150.0	7469.0	614.9	27.33
	3	21/09/10	150.1	150.0	150.0	7311.0	610.7	27.14
Average result							**608.83**	**26.93**
SH5	1	01/10/10	150.0	150.0	150.0	7339.0	620.5	27.57
	2	01/10/10	150.0	150.0	150.0	7337.0	600.3	26.68
	3	01/10/10	150.0	150.0	150.0	7442.0	633.0	28.13
Average result							**617.93**	**27.46**
SH10	1	01/10/10	150.0	150.0	150.1	7642.0	689	30.62
	2	01/10/10	150.0	150.0	150.1	7644.0	696.5	30.96
	3	01/10/10	150.0	149.0	150.0	7571.0	692.2	30.76
Average result							**692.57**	**30.78**
SH15	1	02/09/10	150.0	150.0	150.2	7563.5	680.3	30.23
	2	02/09/10	150.0	150.1	150.0	7506.5	693.4	30.81
	3	02/09/10	150.2	150.2	150.2	7952.5	690.3	30.67
Average result							**688.0**	**30.57**
SH20	1	02/09/10	150.0	150.1	150.2	7492.0	690.30	30.67
	2	02/09/10	150.0	150.0	150.0	7473.0	691.30	30.72
	3	02/09/10	150.0	150.0	150.0	7467.0	691.30	30.72
Average result							**690.96**	**30.70**

APPENDIX-G

Seven Days Compressive Strength of Concrete Specimens Prepared By Sand Blended With Marble Waste Powder

Mix code	Specimen No	Casting date	Dimensions of prism (mm)			Weight (g)	Test result at seven days	
			L	W	H		Failure load(kN)	Compressive strength(MPa)
SM0	1	15/09/10	150.0	150.1	150.2	7492.0	427.2	18.98
	2	15/09/10	150.0	150.0	150.0	7473.0	418.6	18.60
	3	15/09/10	150.0	150.0	150.0	7467.0	416.1	18.49
Average result							**420.63**	**18.69**
SM5	1	28/09/10	150.0	150.0	150.2	7450.0	427.0	18.98
	2	28/09/10	150.0	150.0	150.2	7402.0	434.6	19.31
	3	28/09/10	150.0	150.0	150.0	7301.0	430.5	19.13
Average result							**430.7**	**19.14**
SM10	1	29/09/10	150.0	150.0	150.2	7422	445.1	19.78
	2	29/09/10	150.0	150.0	150.2	7450	419.8	18.66
	3	29/09/10	150.0	150.0	150.4	7651	434.2	19.33
Average result							**433.0**	**19.26**
SM15	1	30/09/10	150.0	150.2	150.2	7523.0	421.5	18.74
	2	30/09/10	150.3	150.3	150.4	8034.0	455.8	20.26
	3	30/09/10	150.0	150.2	150.2	7725.0	452.2	20.10
Average result							**443.1**	**19.7**
SM20	1	30/09/10	150.0	150.0	150.1	7538.0	452.2	20.10
	2	30/09/10	150.0	150.1	150.1	7413.0	403.7	17.94
	3	30/09/10	150.1	150.2	150.3	7970.0	485.3	21.57
Average result							**447.06**	**19.87**

SH0	1	21/09/10	150.0	150.0	150.2	7438.0	853.8	37.95
	2	21/09/10	150.0	150.0	150.2	7411.0	834.2	37.07
	3	21/09/10	150.0	150.0	150.2	7518.0	855.8	38.03
Average result							**847.93**	**37.68**
SH5	1	01/10/10	150.0	150.1	150.2	7553.0	955.30	42.21
	2	01/10/10	150.0	150.2	150.3	7479.0	930.70	41.12
	3	01/10/10	150.0	150.1	150.2	7170.0	893.30	39.47
Average result							**926.43**	**40.93**
SH10	1	01/10/10	150.0	150.0	150.3	7470.0	960.7	42.45
	2	01/10/10	150.0	150.0	150.2	7515.0	925.7	41.14
	3	01/10/10	150.0	150.1	150.2	7502.0	830.3	36.90
Average result							**905.5**	**40.16**
SH15	1	02/09/10	150.0	150.2	150.0	8106.0	913.8	40.61
	2	02/09/10	150.0	150.0	150.0	7657.0	901.5	40.07
	3	02/09/10	150.0	150.0	150.0	7636.0	929.1	41.28
Average result							**914.80**	**40.65**
SH20	1	02/09/10	150.0	150.0	150.2	7665.0	919.3	40.86
	2	02/09/10	150.3	150.3	150.5	8233.0	863.0	38.35
	3	02/09/10	150.0	150.0	150.2	7721.0	933.90	41.50
Average result							**905.40**	**40.23**

APPENDIX-H

Twenty Eight Days Compressive Strength of Concrete Specimens Prepared By Sand Blended With Marble Waste Powder

Mix code	Specimen No	Casting date	Dimensions of prism (mm)			Weight (g)	Test result at twenty eight days	
			L	W	H		Failure load(kN)	Compressive strength(MPa)
SM0	1	15/09/10	150.0	150.2	150.0	7463.0	635.7	28.25
	2	15/09/10	150.0	150.0	150.0	7375.0	680.4	30.24
	3	15/09/10	150.0	150.2	150.0	7952.0	636.7	28.30
Average result							**650.9**	**28.93**
SM5	1	28/09/10	150.0	150.0	150.2	7416.0	664.3	29.52
	2	28/09/10	150.0	150.0	150.3	7393.0	663.3	29.47
	3	28/09/10	150.0	150.2	150.2	7507.0	668.9	29.72
Average result							**665.5**	**29.57**
SM10	1	29/09/10	150.1	150.2	150.3	7548.0	654.3	29.07
	2	29/09/10	150.0	150.1	150.2	7685.0	673.3	29.91
	3	29/09/10	150.0	150.2	150.3	7676.0	668.9	29.72
Average result							**665.50**	**29.57**
SM15	1	30/09/10	150.0	150.0	150.1	7593.0	677.2	30.08
	2	30/09/10	150.2	150.0	150.1	7438.0	673.3	29.91
	3	30/09/10	150.0	150.2	150.2	7668.0	688.9	30.60
Average result							**679.8**	**30.20**
SM20	1	30/09/10	150.0	150.0	150.1	7351.0	670.2	29.77
	2	30/09/10	150.0	150.0	150.2	7438.0	694.3	30.84
	3	30/09/10	150.0	150.2	150.2	7473.0	689.9	30.65
Average result							**684.8**	**30.42**

SH0	1	21/09/10	150.0	150.0	150.2	7427.0	1123.8	49.95
	2	21/09/10	150.2	150.0	150.1	7439.0	1139.8	50.65
	3	21/09/10	150.2	150.0	150.2	7509.0	976.0	43.38
Average result							**1079.8**	**47.99**
SH5	1	01/10/10	150.0	150.0	150.3	7697.0	1173.2	52.13
	2	01/10/10	150.0	150.0	150.2	7739.0	1045.5	46.44
	3	01/10/10	150.0	150.3	150.5	8203.0	1127.6	50.09
Average result							**1115.4**	**49.55**
SH10	1	01/10/10	150.0	150.0	150.2	7737.0	1213	53.90
	2	01/10/10	150.0	150.3	150.3	7892.0	1118	49.72
	3	01/10/10	150.0	150.1	150.2	7693.0	1124	49.96
Average result							**1151.6**	**51.19**
SH15	1	02/09/10	150.2	150.0	150.2	7539.0	1130.3	50.22
	2	02/09/10	150.0	150.0	150.2	7373.0	1123.8	49.93
	3	02/09/10	150.0	150.2	150.3	7299.0	1144.3	50.84
Average result							**1132.8**	**50.33**
SH20	1	02/09/10	150.0	150.0	150.1	7755.0	1105.2	49.10
	2	02/09/10	150.0	150.2	150.0	7803.0	1142.2	50.76
	3	02/09/10	150.0	150.0	150.2	7803.0	1052.1	48.09
Average result							**1099.8**	**49.31**

Appendix I

Twenty Eight Days Flexural Strength of Concrete Specimens Prepared By Cement Blended With Marble Waste Powder

Code	No	Dimensions (cm)			P [kN]	M [N.m]	I [M^4]	C [cm]	σ [MPa]
		L	B	D					
CM0	1	50.00	10.00	10.00	3.64	455.00	8.33E-06	5.00	2.73
	2	50.00	10.00	10.00	3.79	474.00	8.33E-06	5.00	2.85
	3	50.00	10.00	10.00	4.05	507.00	8.33E-06	5.00	3.04
Mean									**2.87**
CM5	1	50.00	10.00	10.00	3.64	455.00	8.33E-06	5.00	2.73
	2	50.00	10.00	10.00	3.74	468.00	8.33E-06	5.00	2.81
	3	50.00	10.00	10.00	3.64	455.00	8.33E-06	5.00	2.73
Mean									**2.76**
CM10	1	50.00	10.00	10.00	3.33	416.00	8.33E-06	5.00	2.49
	2	50.00	10.00	10.00	3.12	390.00	8.33E-06	5.00	2.34
	3	50.00	10.00	10.00	3.43	429.00	8.33E-06	5.00	2.57
Mean									**2.47**
CM15	1	50.00	10.00	10.00	3.27	409.00	8.33E-06	5.00	2.46
	2	50.00	10.00	10.00	3.12	390.00	8.33E-06	5.00	2.34
	3	50.00	10.00	10.00	3.12	390.00	8.33E-06	5.00	2.34
Mean									**2.38**
CM20	1	50.00	10.00	10.00	2.65	331.00	8.33E-06	5.00	1.99
	2	50.00	10.00	10.00	3.54	442.00	8.33E-06	5.00	2.65
	3	50.00	10.00	10.00	3.33	416.00	8.33E-06	5.00	2.49
Mean									**2.38**
CH0	1	50.00	10.00	10.00	4.99	624.00	8.33E-06	5.00	3.74
	2	50.00	10.00	10.00	4.94	617.00	8.33E-06	5.00	3.71
	3	50.00	10.00	10.00	5.09	637.00	8.33E-06	5.00	3.82
Mean									**3.76**

CH5	1	50.00	10.00	10.00	3.85	481.00	8.33E-06	5.00	2.89
	2	50.00	10.00	10.00	5.41	676.00	8.33E-06	5.00	4.06
	3	50.00	10.00	10.00	5.25	656.00	8.33E-06	5.00	3.94
Mean									**3.63**
CH10	1	50.00	10.00	10.00	3.43	429.00	8.33E-06	5.00	2.57
	2	50.00	10.00	10.00	4.68	585.00	8.33E-06	5.00	3.11
	3	50.00	10.00	10.00	4.94	617.00	8.33E-06	5.00	3.71
Mean									**3.13**
CH15	1	50.00	10.00	10.00	4.63	578.00	8.33E-06	5.00	3.47
	2	50.00	10.00	10.00	4.37	546.00	8.33E-06	5.00	3.28
	3	50.00	10.00	10.00	4.26	533.00	8.33E-06	5.00	3.19
Mean									**3.31**
CH20	1	50.00	10.00	10.00	4.10	513.00	8.33E-06	5.00	3.81
	2	50.00	10.00	10.00	3.95	494.00	8.33E-06	5.00	2.96
	3	50.00	10.00	10.00	4.99	624.00	8.33E-06	5.00	3.74
Mean									**3.50**

APPENDIX J

Twenty Eight Days Flexural Strength of Concrete Specimens Prepared By Sand Blended With Marble Waste Powder

Code	No	Dimensions (cm)			P [kN]	M [N.m]	I [M^4]	C [cm]	σ [MPa]
		L	B	D					
SM0	1	50.00	10.00	10.00	3.64	455.00	8.33E-06	5.00	2.73
	2	50.00	10.00	10.00	3.79	474.00	8.33E-06	5.00	2.85
	3	50.00	10.00	10.00	4.06	507.00	8.33E-06	5.00	3.04
Mean									**2.87**
SM5	1	50.00	10.00	10.00	4.73	592.00	8.33E-06	5.00	3.55
	2	50.00	10.00	10.00	4.89	611.00	8.33E-06	5.00	3.67
	3	50.00	10.00	10.00	4.73	592.00	8.33E-06	5.00	3.55
Mean									**3.59**
SM10	1	50.00	10.00	10.00	4.73	605.00	8.33E-06	5.00	3.55
	2	50.00	10.00	10.00	4.84	624.00	8.33E-06	5.00	3.63
	3	50.00	10.00	10.00	4.99	644.00	8.33E-06	5.00	3.74
Mean									**3.64**
SM15	1	50.00	10.00	10.00	5.15	618.00	8.33E-06	5.00	3.86
	2	50.00	10.00	10.00	4.94	592.00	8.33E-06	5.00	3.71
	3	50.00	10.00	10.00	4.73	637.00	8.33E-06	5.00	3.56
Mean									**3.71**
SM20	1	50.00	10.00	10.00	5.10	605.00	8.33E-06	5.00	3.82
	2	50.00	10.00	10.00	4.84	637.00	8.33E-06	5.00	3.63
	3	50.00	10.00	10.00	5.10		8.33E-06	5.00	3.82
Mean									**3.76**
SH0	1	50.00	10.00	10.00	4.99	618.00	8.3E-06	5.00	3.74
	2	50.00	10.00	10.00	4.94		8.3E-06	5.00	3.71
	3	50.00	10.00	10.00	5.10	598.00	8.3E-06	5.00	3.82
Mean									**3.76**

SH5	1	50.00	10.00	10.00	4.78	598.00	8.3E-06	5.00	3.59
	2	50.00	10.00	10.00	4.78	598.00	8.3E-06	5.00	3.59
	3	50.00	10.00	10.00	4.84	605.00	8.3E-06	5.00	3.63
Mean									**3.60**
SH10	1	50.00	10.00	10.00	5.10	637.00	8.3E-06	5.00	3.82
	2	50.00	10.00	10.00	5.04	631.00	8.3E-06	5.00	3.78
	3	50.00	10.00	10.00	5.30	663.00	8.3E-06	5.00	3.99
Mean									**3.86**
SH15	1	50.00	10.00	10.00	5.36	669.00	8.3E-06	5.00	4.02
	2	50.00	10.00	10.00	4.99	624.00	8.3E-06	5.00	3.74
	3	50.00	10.00	10.00	5.20	650.00	8.3E-06	5.00	3.90
Mean									**3.89**
SH20	1	50.00	10.00	10.00	5.10	669.00	8.3E-06	5.00	3.82
	2	50.00	10.00	10.00	5.36	637.00	8.3E-06	5.00	4.02
	3	50.00	10.00	10.00	5.30	669.00	8.3E-06	5.00	3.98
Mean									**3.94**

APPENDIX-K

Water Penetration Depth of Concrete Specimens, at Forty Days Testing Age

Code	Class	D_1(mm)	D_2(mm)	D_3(mm)	D_4(mm)	D_5(mm)	Average(mm)	D_{max}(mm)
CM0=SM0	C-25	30	15	26	19	22	22.4	30
CM5	C-25	29	24	20	28	13	22.8	29
CM10	C-25	27	27	26	14	26	24.0	27
CM15	C-25	17	18	28	15	17	19.4	28
CM20	C-25	24	13	28	19	18	20.4	28
CH0=SH0	C-50	5	2	9	6	4	5.2	9
CH5	C-50	4	3	5	3	3	3.6	5
CH10	C-50	10	4	6	3	5	5.6	10
CH15	C-50	8	5	11	6	10	8.0	11
CH 20	C-50	13	4	12	9	12	10.0	13
SM0=CM0	C-25	30	15	26	19	22	22.4	30
SM5	C-25	10	3	16	9	12	10.0	12
SM10	C-25	10	5	12	4	12	8.6	12
SM15	C-25	12	7	8	7	6	8.0	12
SM 20	C-25	8	6	11	9	9	8.6	11
SH0=CH0	C-50	5	2	9	6	4	5.2	9
SH 5	C-50	5	4	7	8	3	5.4	8
SH10	C-50	5	5	7	8	1	5.2	`8
SH15	C-50	5	7	5	3	3	4.6	7
SH20	C-50	4	5	5	3	3	4.0	5

APPENDIX-L

Photo Attachments

Photo 1: Batching and blending of marble waste powder with cement

Photo 2: Batching and blending of marble waste powder with sand

Photo 3: Mixing of concrete

Photo 4: Slump measurement

Photo 5: Placing of concrete into mold

Photo 6: Concrete specimens after casting

Photo 7: Concrete specimens in curing pond

Photo 8: Concrete specimens arranged for test

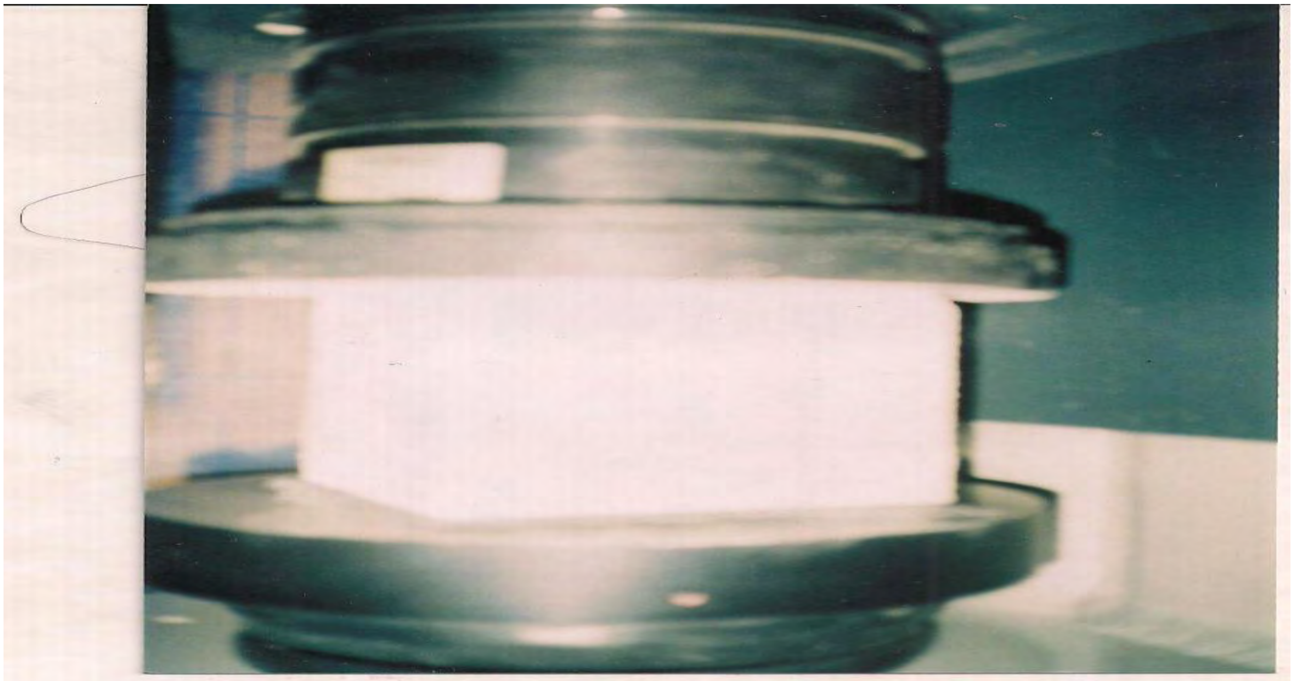

Photo 9: Concrete specimen on compressive strength testing machine

Photo 10: Concrete specimen during flexural strength test

Photo 11: Water permeability testing apparatus

Photo 12: Arranging concrete specimens for water permeability test

DECLARATION

This thesis is a result of my original work and it has not been presented for a degree programme in any other university. Furthermore, all sources of material used for the thesis have been duly acknowledged.

Candidate

Name______________________

Signature___________________

SIGNED DECLARATION SHEET

Submitted by

Student **Signature** **Date**

Approved by

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Advisor **Signature** **Date**

2.

Chairperson, Dept's **Signature** **Date**

Graduate Committee

3.

Chairperson, Faculty's **Signature** **Date**

Graduate Committee

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Dean, Graduate School **Signature** **Date**