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

UTILIZATION OF WASTE MARBLE POWDER AS A PARTIAL REPLACEMENT OF CEMENT IN HCB PRODUCTION

A Thesis in Construction Technology and Management Stream, Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

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DECLARATION

I the undersigned, declare that this thesis is my original work and it has not been presented for a degree in any other university and that all sources of materials used for the thesis have been duly acknowledged.

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ABSTRACT

Hollow concrete blocks are one of the most extensively used wall construction material in major cities of our country, Ethiopia. Aggregates, cement, and water are the main materials required for the production of this building material. To achieve the required physical strength and dimensions of requirements and standards, they are manufactured from concrete and processed into molds. While comparing with others, HCB masonry is believed to be cost and time efficient and economical solution in construction.

The production of cement is one of the environmentally unfriendly processes due to the release of CO_2 gas to the atmosphere. In addition to its negative environmental impact cement is also one of the most expensive materials when compared to the other constituents of the HCB. On the other hand, marble processing factories have a problem of disposing of the waste marble powder. Using marble waste powder in HCB production, the effects of partial replacement of cement with marble waste powder on the performance of HCB was investigated. The physical properties and compressive strength of 288 HCBs were determined.

The laboratory-based investigation for the partial replacement of cement with marble powder in HCB production was conducted. Tests on the suitability of materials used and their performance in terms of known engineering properties were carried out. The focus was the partial replacement of cement with marble powder in the order of, 0%(Control), 10%, 20%, and 30% of cement by weight for Class A, B and C HCBs of size 20x20x40cm.

Replacement at 10%, 20%, and 30% ranges result in compressive strength reduction than that of 100% cement. However, the compressive strength of blended cement with 10% to 30% replacement ranges satisfy the minimum compressive strength set by Ethiopian standard of HCB for class A, B and C. Other properties of marble waste blended cement of HCBs such as density and water absorption remain within the acceptable limits of Ethiopian standard. Therefore, further investigation should be made for more percentage of marble waste replacement.

Keywords: *Compressive strength, Hollow concrete block, Load bearing, Marble waste, Non- load bearing.*

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LIST OF ABBREVATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing Materials
BS	British Standard
CEM II	Portland-composite cement
CSH	Calcium Silicate Hydrate
ES	Ethiopian Standard
EN	European Standard
Eq	Equation
GTZ	Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
HCB	Hollow Concrete Block
IS	Indian Standard
PPC	Portland Pozzolana Cement
SCC	Self-Compacting (Consolidated) Concrete

CHAPTER ONE

INTRODUCTION

1.1 General

Appropriate shelter is one of the basic requirement of human beings. In ancient time, the man started taking shelter in caves, excavated below ground level and under hanging mountain cliff, and this type of shelter just provided a safe place from environmental extremities. The concept of stability and safety as per structural features of shelter were completely out of mind. With the development and maturity of human mind, the man began to modify the structural formation of shelter to address the increasing needs and facilities, which an optimum shelter design possessed. After achieving a feat by the use of easily available material like mud in the construction of walls and then the technique of burnt clay brick masonry to form a structural part of the shelter, there was, still a long journey is coming out for the best possible material for construction of stable and safe structural units of shelter. The desire for the search of safe and stable structural materials keeping in view the economy of whole structure, paved way for usage of hollow concrete blocks [1].

Nowadays, hollow concrete blocks are becoming very popular. These blocks are being widely used in the construction of residential buildings, factories, and multi-storied buildings. Hollow concrete blocks are more useful due to their lightweight and ease of ventilation. The blocks and bricks are made out of a mixture of cement, sand and stone chips. Hollow concrete blocks construction provides facilities for concealing electrical conduit, water, and soil pipes. It saves cement in masonry work, bringing down cost of construction considerably. The economy of the structure is one of the basic aspects upon which any design is based. The stability plays an important role but the best designer is one who comes out with design, which gives the stable and economic structure. The development of the construction technology is closely related to the development of adequate mechanization and handling technology. Hollow concrete is an important addition to the types of masonry units available to the builders and its use for masonry is constantly increasing [1].

Hollow concrete blocks are one of the most extensively used walling materials. Some of the reasons for this is their relatively low cost when compared to wall with reinforced concrete and speed of installation by semi-skilled labourers. HCB walls are weak against lateral loads. Adding steel reinforcing bars vertically and horizontally inside the HCBs can increase their resistance to lateral loads [2]. This construction material is one of the most widely used walling material in major cities of our country, Ethiopia.

Materials required for the production of HCB are aggregates, that is, sand, gravel, red ash or pumice. They should be clean and stored separately close to the mixing plant. All aggregates used for the production have to be approved by an independent concrete laboratory. Water for mixing must be clean and free of impurities, cement and machinery for production & equipment for transportation are main materials for the production of HCBs [3].

Among the materials in use for the production of the hollow concrete block, cement is the most expensive material. Moreover, the production of cement is one of the environmentally unfriendly processes due to the release of CO_2 gas to the atmosphere. Therefore, looking for an alternative cement replacing material is necessary.

Using industrial wastes as blending materials in cement has technical, economic and environmental benefits besides the reduction of CO_2 gas emission from cement production. The economic benefit usually attributes to the reduction of the amount of expensive or scarce ingredients with cheap materials. Environmentally, when industrial wastes are recycled not only the CO_2 emission reduced but also residual products from other industries are reused and therefore less material is dumped as landfill and more natural resources are saved [4].

Marble waste powder, which is a by-product of marble processing factory; was studied by Abrar Awol in 2011 for its use in concrete as a cement replacing material. The research showed positive results or comparable result with cement not replaced by marble waste powder and benefits up to 5 percent replacement [5].

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 a 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 the water containing marble powder. The water is reused until it gets thick enough [6].

According to Ato Habtom Kassahun who is the project manager of Kara marble processing Enterprize, out of 50 kg marble block, 10 kg of marble is lost as a waste during polishing and 5 kg is lost during cutting and giving different shapes.

As marble is the derivative of limestone with the 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.

1.2 Statement of the problem

The production of cement is one of the environmentally unfriendly processes due to the release of CO_2 gases to the atmosphere. It is believed that one ton of Portland cement clinker production creates about one ton of CO_2 and other greenhouse gases [7]. This shows that the cement industry contributes to today's worldwide concern, which is global warming. This endangers the sustainability of the cement industry.

In addition to its negative environmental impact cement is also one of the most expensive materials when compared to the other constituents of concrete or hollow concrete blocks. The raw materials for the cement production like lime are also being exploited in a large amount, which may result in running out of them, as it is predicted to happen in some places of the World [7].

Currently, there are more than fourteen marble processing plants in Ethiopia located in different towns. In Ethiopia 409,374.00, 572,421.00, 613,820.00, 770,000.00 and 1,000,000.00 m^2 of marble commodities were produced in the year 2009,2010,2011,2012 and 2013 respectively [8] which implies that 30% of this mineral was lost as waste. Currently the amount of loss as waste is increasing as more companies joined the industry than before.

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

- 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.
- 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.
- When dumped along a catchment area of natural rainwater, it results in contamination of over groundwater reservoir and causes drainage problem [5].

Thus, this research deals with checking the feasibility of the marble byproduct powder or dust which is left as a waste in marble factories for using it as a partial cement replacement material in hollow concrete blocks production.

1.3 Objectives

1.3.1 General Objective

The aim of this research is to study the possibility of using waste marble powder or dust as a partial replacement of cement in hollow concrete block production under the local conditions in Addis Ababa.

1.3.2 Specific Objectives

The specific objectives of this research work are expressed as follows:

1. To determine replacement rates at which marble powder can be effectively put into service in hollow concrete block production.
2. To experimentally investigate the effects of marble powder in HCB production using density, water absorption and compressive strength tests of produced blocks.

Finally, after making such study on the waste marble powder or dust the thesis drew some conclusions and recommendations on the results and various aspects of the material as a partial replacement of cement in hollow concrete blocks production.

1.4 Scope of the study

The research addresses, studying the chemical composition of marble waste powder or dust and physical properties of materials used for manufacturing HCBs like density, water absorption and compressive strength of produced hollow concrete blocks of blended waste marble powder or dust and cement. Throughout the investigation, the research is limited to marble waste powder or dust from Kara marble processing enterprise, which process limestone and marble.

1.5 Structure of the thesis

The research is organized into five chapters and each chapter contains a number of sections and further subsections. A general introduction provided along with the research objective and significance in the first chapter. In Chapter two, a comprehensive review of hollow concrete blocks and marble are presented.

Chapter three used entirely to describe methodology and materials used in the research. It explains properties of materials, mix proportions, mixing, casting, and curing procedures used in the attempt to find out in a systematical and scientific study.

Chapter four covers the experimental program of the study, results, and discussions of the tests carried out during this study.

Conclusions are in chapter five together with recommendations for further research work. This followed by an extensive list of references. The Annexes give the results of the individual tests, other relevant data and representative photos taken during the research work.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

There is a great impetus worldwide towards using industrial waste by-products. Leaving the waste material to the environment directly can cause environmental problems. Therefore, many countries have still been working on how to use the waste material so that they give fewer hazards to the environment [6].

Waste material 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 [7]. The addition of inactive materials or fillers, principally limestone, is increasingly accepted in European Countries since the European Standard for common cement is first published in 1992 as pre-standard ENV 197-1. There has been an increasing trend in the use of limestone as a mineral additive in cement not only in the European countries but also in other parts of the world [8].

The major by-product in the construction industry is marble waste, which is produced in significant amounts in different countries. Marble blocks are cut into smaller blocks in order to give the required smooth shape. During the cutting and polishing processes about 30% marble results in dust, mainly composed of SiO_2, Al_2O_3, Fe_2O_3 and CaO, with some minor constituents such as Mg, Ti, Mn and K oxides, which can cause serious damages to the environment, such as soil and underground water contamination, if not efficiently treated before disposal.

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.

Therefore, the main objective of this work is to study the possibility to incorporate marble wastes in hollow concrete blocks production, without to degrade their properties as a partial replacement of cement.

2.2 Hollow concrete block production

Masonry is the assemblage of building units joined with the help of cementitious material or any accepted joining material to perform the required function.

The hollow concrete block is an alternative wall and floor making material in the building construction having one or more large holes with the solid material between 50 and 75 percent of the total volume of the block calculated from the overall dimensions [9].

Most hollow concrete blocks have one or more hollow cavity manufactured from a zero slump mixture of Portland cement, aggregates, water and sometimes admixtures.

2.2.1 Hollow concrete filler blocks for ribbed slabs

Hollow concrete filler blocks for a ribbed slab shall be manufactured in the approved vibrated machine and its production is done the same way as the production of wall hollow concrete blocks. According to Indian standard IS 6061(Part I)-1971, hollow concrete filler blocks specify to confirm requirements for size and shape and breaking strength. A typical section of the hollow concrete filler blocks to span between joists kept at 600mm centers. If the hollow concrete filler block has to span between joists kept at 750mm centers or above, the block should be suitably reinforced [10].

2.2.1.1 Breaking strength test on hollow cement concrete filler block

According to IS 6061(Part I)-1971, filler hollow concrete blocks shall be suitably and simply supported without any mortar at the supports and having a bearing of at least 25mm on the supports placed at 600mm center to center. A load of 300kg shall be applied on a steel plate 20mm wide kept centrally over the entire width of the block and parallel to the supports. The stripping load of 300kg is applicable only for blocks having a width of 250mm and for wider blocks, the load should be increased in proportion to the actual width and 250mm. The block shall not break or crack or show any type of deformation. At least two blocks from the lot manufactured in a day or two blocks from 1000 blocks whichever is less should be tested for dimensions and breaking strength. On the other hand, Ethiopian standard ES596:2001 recommends class D strength (average strength of 6 hollow blocks not less than 2 MPa and individual strength not less than 1.8 MPa). It is done by taking six full-size samples from 5000 blocks for the compression test. If blocks are kept in batches, at least three samples shall be taken from each.

2.2.2 Hollow concrete blocks for wall construction

Concrete blocks are masonry units, usually solid or with single or multiple hollows, made of various ingredients: cement, aggregate such as sand, gravel, crushed stones, air-cooled slag, coal, cinders, expanded shale or clay, expanded slag, volcanic cinder(pozzolana), pumice and scoria and water. Hollow concrete blocks used for wall construction are classified as load bearing and non-load bearing depends on their structural function [11]. According to ASTM C90-05 hollow load bearing concrete blocks have three weight classifications those are normal weight, medium weight and lightweight blocks as listed in Table 2.1.

Table 2.1 Weight classification of hollow concrete block [12].

Classification of Hollow block	Weight classification- Oven-Dry Density of hollow block concrete, kg/m3
Light-weight	Less than 1680
Medium weight	1680 to less than 2000
Normal weight	2000 or more

On the other hand, non-load bearing hollow concrete blocks are manufactured in accordance with the specification of ASTM C129-03. Those blocks intended for use in non-load bearing partitions, but under certain conditions may be suitable for use in non-load bearing walls above grade, where effectively protected from the weather.

According to Ethiopian standards ES 596:2001 hollow concrete block shall conform to four classes depends on their strength, as Class A, B, C and D and their requirements are defined below and their minimum comprehensive strength listed in Table 2.2. On the other hand, Indian standard recommended classes of hollow concrete blocks as A, B, and C but class D manufactured as solid block used for the purpose of load bearing wall.

Class A hollow concrete blocks are used for load bearing wall construction above or below ground level, in damp proof course, in exterior walls that may or may not be treated with weather-protective coating and for interior walls and density of class A blocks must be in the range of 900-1,200 kg/m^3. On the other hand, Indian standard IS: 2185-1-2005 recommended a minimum block density of 1,500 kg/m^3 and minimum average compressive strength of 3.5 N/mm^2 at the age of 28 days.

Class B and C hollow concrete blocks are used for load bearing wall construction above ground level in damp proof course, in exterior walls that are treated with suitable weather-protective coating and their density should be between 900 - 1,200 kg/m^3. On the other hand, Indian standard IS: 2185-1-2005 recommended minimum density within the range of 1,100 - 1,500 kg/m^3 and minimum average compressive strength of 3.5 N/mm^2 at 28 days.

Class D are used for non-load bearing interior walls and exterior panels walls in steel or reinforced concrete framed construction when protected from weather by rendering or by some other efficient treatment and their density should be between 600-900 kg/m^3[9]. Indian standard IS: 2185-1-2005 recommended, the solid concrete blocks are used as load bearing units and shall have a block density not less than 1,800 kg/m^3 and minimum average compressive strength of 4.0 N/mm^2 at 28 days.

Table 2.2. The comprehensive strength of hollow concrete blocks at 28 days [ES 596:2001]

Type of hollow concrete block	Class	Minimum comprehensive strength(N/mm^2)	
		Average of 6 units	Individual units
Load bearing	A	5.5	5.0
	B	4.5	4.0
	C	3.5	3.0
Non load bearing	D	2.0	1.8

2.2.3 Hollow concrete blocks production process

2.2.3.1 Raw Materials

Portland pozzolana cement, aggregates and water are commonly raw materials used to make the concrete mixture for production of hollow concrete blocks. However, the concrete mixture used for the block has a higher percentage of sand and a lower percentage of gravel and water than the concrete mixtures used for general construction purposes. This produces a very dry, stiff mixture that holds its shape when it is removed from the block mold. In addition to these, basic components various chemicals, called admixtures, can be used to alter curing time, increase compressive strength, or improve workability sometimes pigments may be added to give the blocks a uniform color throughout. Aggregates should pass through a sieve of the nominal aperture of 9.5mm in addition to this the size of aggregate should not exceed two–thirds of the thickness of the thinnest part of the shell or web unit [9].

2.2.3.2 Mixing

In case when hand mixing is permitted by the Engineer-in-charge, it shall be carried out on a water-tight platform and care shall be taken to ensure that mixing is continued until the mass is uniform in colour and consistency. Too little water causes the mix to be friable, while too much water causes difficulty in the immediate withdrawal of the mold. Ten percent extra cement may be added if hand-mixing is an alternative according to Indian standard IS: 2185-(part II)-1983.

In case of machine-molded blocks, batching of the ingredients should be done accurately and concrete mixing shall be done in a mixer to achieve homogeneous mix. Mixing shall be continued until there is a uniform distribution of the materials, and the mass is uniform in colour and consistency according to IS: 2185-1-2005. The web markings on the units as they come from the machine give a good indication as to whether the proper consistency of concrete has been used. In addition to the grading of the aggregate and the quantity of cement, the amount of water required for mix will depend to an extent on the type of machine on which blocks are produced. It is possible to judge the proper consistency by squeezing a handful of the concrete mixture.

2.2.3.3 Compaction and placing

According to Indian standard IS:2185 -2- 1983, in the case of a hand-operated machine, the mixture shall be placed into the mold in layers of about 50 to 75mm and each layer thoroughly tamped with suitable tamper until the whole mold is filled up and struck off level with a trowel. In the case of mechanical compaction, the mold shall be filled up to overflow, vibrated or mechanically tamped and struck off level. After remolding, the blocks shall be protected against sun and wind by placing on the shade until they are sufficiently hardened to permit handling without damage.

On the other hand, GTZ low-cost housing manual Volume I specify to vibrate the mixture for 60 seconds before extruded as a hollow concrete block and transported and remains for 24 hours on a wooden pallet then it is being cured covered by a plastic sheet to enhance the curing process and preventing the water from evaporation.

2.2.3.4 Curing

Indian standard IS: 2185-2-1983 recommends as immediately the block is made, it shall be released from the mould and removed with the pallet to a covered shed, to protect it against sun and strong winds. The blocks shall be stored in the shed until they are sufficiently hardened to permit handling without damage but in no case shall this period be less than 12 hours. The blocks hardened in accordance shall then be removed from the pallets and placed in a curing water tank or taken to the curing yard where these shall be kept continuously moist for at least 21 days. The blocks shall be stocked on a clean and level platform free from earth or other impurities during the curing process and shall be stocked in honeycomb fashion with voids horizontal to facilitate through the passage of air.

On the other hand, GTZ low-cost housing manual Volume I recommends 10 days of curing time, in addition to this, date of production must be written on blocks for the purpose of identification whether it is ready or not for construction.

2.2.3.5 Surface texture and finish

Concrete masonry units can be given a variety of surface textures ranging from a very fine close texture to a coarse open texture by the proper selection, grading, and proportioning of aggregates at the time of manufacture. Textures may also be developed by treating the face of the units while still green by wire brushing or combing, by slightly eroding the surface by playing a fine spray of water upon it, and by splitting (split block) such surface must provide adequate adhesion for plaster or other finish as stated in Ethiopian standard ES 596:2001.

Colour may be introduced by incorporating non-fading mineral pigments in the facing concrete, or by applying a coloured cement grout or paint to the face of the units soon after they are removed from the molds. Selected coloured aggregates may also be used in the facing and exposed by washing with water or dilute hydrochloric acid.

When face units are required to have coloured surfaces the colour shall be as agreed upon between the manufacturer and the purchaser and the manufacturer shall supply to the purchaser for his retention three units of the agreed colour to serve as an example of the possible range of such colour. For the purpose of assessing the uniformity of colour and texture, the manufacturer shall by agreement with the purchaser', submit for the purchaser's approval a sample of 10 units, 5 of which are to be retained by the purchaser and 5 by the manufacturer as stated in Ethiopian standard ES 596:2001.

2.2.4 Physical requirements

2.2.4.1 General

All units shall be sound and free of cracks or other defects, which interfere with the proper placing of the unit or damage the strength or performance of the construction. Minor chipping resulting from the customary methods of handling during delivery, shall not be deemed grounds for rejection. Where units are to be used in exposed wall construction, the face or faces that are to be exposed shall not show chips or cracks, not otherwise permitted, or other imperfections when viewed from a distance of not less than 6.1 m under diffused lighting. Five percent of a shipment containing chips, not larger than 25.4 mm in any dimension, or cracks not wider than 0.5 mm and not longer than 25% of the nominal height of the unit [ASTM C90-05] or 10mm [ES 596:2001] or 25 mm [IS: 2185-1-2005], this shall not be deemed grounds for rejection.

2.2.4.2 Dimension and Tolerance of Hollow concrete block

Hollow concrete block shall be referred by its nominal dimensions. Standard dimensions of units are the manufacturer's designated dimensions. Nominal dimensions of modular size units are equal to the standard dimensions plus the thickness of one mortar joint. For modular size units' nominal dimension equal to standard dimension plus 9.53mm but for non-modular size units, it exceeds the standard dimension by 3.2 to 6.4 mm [ASTM C129 - 03].

Other standards such as Indian standards [IS:2187-1979] recommended mortar joint 10mm for modular size and 6mm for non-modular ones.

Different standards specify their own limits on the permissible variations in the dimensions of standard hollow concrete block masonry units. These limits make easy laying of the units assist the mason to construct the masonry within the suitable tolerances and help to offer an aesthetic finish and appearance of the constructed masonry.

According to ASTM C90-05 and ASTM C129-03, overall dimensions' tolerance (length, width, and height) of the hollow concrete block shall not differ by more than 3.2mm from the specified standard dimension. In addition to this, face shells and web thickness shall not be less than 13mm for the non-load bearing hollow concrete block. In case of Indian standard IS: 2185:1:2005 overall dimensions shall not differ by ±5mm for length and ±3mm for height and breadth in addition to this face shells and webs thickness shall conform the Table 2.3.

Table 2.3 Minimum face- shall and Web thickness according to IS: 2185:1:2005.

Nominal block width in (mm)	Minimum Face thickness (mm)	Minimum thickness of Web (mm)	Minimum total Web thickness per course in any 200 mm length of wall (mm)
100mm or less than	25	25	25
100 to 150	25	25	30
150 to 200	30	25	30
Over 200	35	30	38

Ethiopian standard [ES 596:2001] specify maximum dimensional variation (length, height, breadth), it should be ±5mm for nominal dimensions of concrete masonry blocks. For any class of unit the nominal dimensions of concrete masonry blocks according to ES 596:2001 are shown in Table 2.4. In addition to this, face shells and webs thickness of hollow units shall be at least one-sixth of overall breadth of a unit or 25mm whichever is the greater.

Table 2.4 Nominal dimensions of concrete masonry blocks according to ES 596:2001.

Length (l) mm	Breadth (b) mm	Height (h) mm
400[1]	100[1]	200[1]
	120[1]	
	150[1]	
	200[1]	
500	100	100
	120	150
	150	200
	200	250
600	100	100
	120	150
	150	200
	200	250
1 Preferred modular sizes.		

2.2.4.3 Block Density

The density of a concrete masonry unit is expressed as the oven-dry density of concrete in kg/m^3 as determined in accordance with ASTM C 140, Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units. The density of a block can only be obtained after the casting process by taking three blocks taken randomly from the selected samples and then dried to constant mass in a suitable oven heated to approximately 105°C. After cooling the blocks to room temperature, the dimensions of each block shall be measured in centimeters (to the nearest millimeter) and the net volume is computed in cubic centimeters. The blocks shall then be weighed in kilograms (to the nearest 10g) and the density of each block calculated as follows:

$$Density = \frac{mass\ of\ block\ in\ kg}{Volume\ of\ speciemen\ in\ cm^3} x10^6\ kg/m^3 \text{…………………Eq. 2.1}$$

Indian standard IS: 2185-(part 1) - 2005 states three blocks shall be taken for average density and the density is calculated by dividing the mass of a block by the overall volume, including holes of cavities and end recesses. Class A units shall have a minimum block of density 1500 kg/m^3 and class B shall have a block density between 1100 kg/m^3 and 1500 kg/m^3. According to Ethiopian standard ES 596:2001 three blocks shall be taken for average density and it should conform to the requirements specified in Table 2.5 below.

Table 2.5 Density classification of concrete masonry units according to ES596:2001

Class of hollow concrete block	Ethiopian standard ES 596:2001 (kg/m^3)
A	900-1200
B	900-1200
C	900-1200
D	600-900

According to Ethiopian Standard Class A, B, C are load bearing units and class D is a non-load bearing unit while in case of Indian standard class A and B are load bearing units and Class C are for non-load bearing units.

2.2.4.4 Compressive Strength

The strength of hollow concrete is closely related to the specimen size and shape, a method of pore formation, the direction of loading, age, water content, water-cement ratio, the degree of compaction, and cement content characteristic of its ingredients used, a method of curing, size and number of holes created. Both hollow structure of the air holes and mechanical condition of the pore shells have a great influence on the compressive strength of the hollow concrete block. It has also been found that a reduction in density due to the formation of holes will result in a significant drop in strength. Generally, compressive strength increases linearly with a density of structural concrete. The minimum compressive strength at 28 days is the average of six units, and the minimum compressive strength at 28 days of individual units should be tested. The compressive strength of a concrete masonry unit shall be taken as the maximum load in Newton divided by the net cross-sectional area of the unit in square millimeters finally the results of the nearest 0.1 N/ mm^2, separately for each unit and as the average for the six units will be recorded [13].

The following are the minimum compressive strength requirements for blocks at the age of 28 days. The mix proportions of the material components are to be adjusted as required to obtain the required compressive strength according to Ethiopian standard, and ASTM standards listed in the Table 2.6 and 2.7. The corresponding lowest minimum crushing strength of any unit shall be not less than 80% of the minimum permissible average crushing strength.

Table 2.6 Comprehensive strength of hollow concrete blocks at 28 days according to ES596:2001

Type of hollow concrete block	Class	Minimum comprehensive strength(N/mm^2)	
		Average of 6 units	Individual units
Load bearing	A	5.5	5.0
	B	4.5	4.0
	C	3.5	3.0
Nonload bearing	D	2.0	1.8

Table 2.7. Comprehensive strength of hollow concrete blocks according to ASTM C90-70

Types of hollow concrete block	Grade	Minimum comprehensive strength (N/mm^2)	
		Average of 3 units	Individual units
Load Bearing	Type N(type I & II)	6.9	5.5
	Type S (type I & II)	4.8	4.1
Non Load bearing	(type I & II)	Average of 5 units	Individual units
		3.5	3.0

2.2.4.5 Water Absorption

It is a measure of the voids (reachable pore volume) within the net volume of the concrete, including the voids within the aggregate itself. According to ASTM C140-70, the water absorption determined from five full-size units completely immersed in water at room temperature for 24 hours and they shall be removed from the water and allowed to drain for one minute by placing them on a 10mm or coarser wire mesh. Visible surface water being removed with a damp cloth, and immediately weighed and then all specimens shall be dried in a ventilated oven at 100°C to 115°C for not less than 24 hours and until two successive weightings at intervals of 2 hours show an increment of loss not greater than 0.2 percent of the last previously determined mass of the specimen and the recommended water absorption requirements of load bearing hollow concrete block in the Table 2.9. On the other hand, Ethiopian standard [ES 596:2001] specify water absorption 290 kg/m^3 (25%) for load bearing hollow concrete block and 320 kg/m^3 (30%) for the non-load bearing hollow concrete block while Indian standard recommended 10 percent.

According to ASTM C 90 - 70 hollow concrete blocks have two grades; those are grade N and grade S. Grade N blocks are suitable for general use such as in exterior walls below and above grade level that may or may not be exposed to moisture penetration. However, grade S blocks are limited to use above grade level for walls not exposed to weather and for exterior walls with weather protective coating. Both grades have two types such as moisture controlled units designed as Type I (N - I and S - I) and non-moisture controlled units designed as type II (N - II and S- II).

Table 2.8. Absorption requirements of the load-bearing Hollow concrete block according to ASTM C90-70

Grade	Water absorption max (kg/m^3)			
	Oven dry weight classification (kg/m3)			
	Light weight		Medium weight	Normal weight
	Less than 1362 (kg/m3)	1362 to less than 1682 (kg/m3)	1682 to less than 2002 (kg/m3)	2002 or more (kg/m3)
N-I & II	-	290	240	210
S-I & II	320	-	-	-

2.2.4.6 Drying Shrinkage

The drying shrinkage is defined as the change in linear dimension of test specimen due to drying from saturated condition to an equilibrium weight and length under specified accelerated drying condition. Dimensional changes of units have a significant effect on cracking that may take place during the early curing and drying which leads to a reduction in volume due to loss of moisture. The amount of drying shrinkage that occurs depends on the properties of the materials used for production, for instance, units produced with normal weight aggregates tend to shrink less than units produced with lightweight aggregates and high strength units, with the corresponding high cement content, will shrink more. In addition to this, the weather conditions at the job site also contribute to the dimensional changes in concrete masonry. Clearly, there will be more shrinkage in hot, arid climates as the amount of moisture lost to the atmosphere is greater than in cooler, humid climates [14].

2.2.4.7. Moisture content

Moisture content requirement of concrete block masonry units is related to their linear shrinkage characteristics. Concrete loses or absorbs moisture with changes in the moisture content or relative humidity of the surrounding air. The cement paste may gain moisture and hence “swell”, or lose moisture and “shrink” before it attains an air-dry equilibrium condition. It will undergo no dimensional change when the moisture content of the concrete is in equilibrium with the relative humidity of the surrounding so that masonry units are never delivered to a construction site in a saturated condition, and moreover, could not be laid in this condition. If unacceptably moist units are laid in a wall at the time of construction, and this inherent shrinkage is restrained in - service, stresses are developed within the masonry that may cause cracking. ASTM C90- 70 specifies three moisture content requirements corresponding to linear shrinkage as listed in Table 2.2 above.

2.2.5. Sampling of hollow concrete blocks

The blocks required for carrying out tests in accordance with Ethiopian standard [ES 596: 2001] by taking a sample of 12 hollow concrete blocks shall be taken from every consignment of 10,000 blocks or part thereof of the same size and same batch of manufacture can be taken from stack in which case the required number of blocks shall be taken at random from across the top of the stacks, the sides accessible and from the interior of the stacks by opening trenches from the top and those block shall be kept under cover and protected from extreme conditions of temperature, relative humidity and wind until they are required for test. The tests shall be undertaken as soon as practicable after the sample has been taken. From these samples, the blocks shall be taken at random for conducting the tests.

All the 12 blocks shall be checked for dimensions and inspected for the visual defect. Out of the 12 blocks, three blocks shall be subjected to the test for block density and water absorption, six blocks to the test for compressive strength and the remaining three blocks shall be reserved for retest purpose.

On the other hand, Indian standard IS 2185 (Part I) - 1979 a sample of 20 blocks shall be taken from every consignment of 5000 blocks. From these samples, 20 blocks shall be checked for dimensions and inspected for visual defects. Out of the 20 blocks, three blocks shall be subjected to the test for block density, eight blocks to the test for compressive strength, three blocks to the test for water absorption and three blocks to the test for drying shrinkage and later to the test for moisture movement. The remaining three blocks shall be reserved for a retest for drying shrinkage and moisture movement if a need arises.

British standard BS: 6073 (part I) 1981 recommended 10 blocks for dimensional, compressive strength and 4 blocks for drying shrinkage testing in every 1,000 blocks but ASTM C 140- 70 for strength, absorption, and moisture content determinations recommended 10 units shall be selected from each lot of 10,000 units of fraction thereof and 20 units from each lot of more than 10,000 and less than 100,000 units. For lots of more than 100,000 units, 10 units shall be selected from every 50,000 units or fraction thereof contained in each lot.

2.2.6. Criteria for conformity of hollow concrete blocks

According to Ethiopian standard [ES 596:2001], the number of units with dimensions outside the tolerance limit and/or with visual defects, among those inspected shall be not more than two. For this comprehensive strength, the mean value determined shall be greater than or equal to the minimum limit specification. For water absorption, the mean value determined shall be equal or less than the maximum limit specified in sec 2.2.4.4 & 2.2.4.5.

Indian standard IS 2185 (Part I)-1 1979 specify hollow concrete blocks to conform dimensions and visual defects, block density, compressive strength, water absorption and drying shrinkage requirements as defined in section 2.2.4.2 to 2.2.4.6. ASTM C90-70 recommend conforming the requirements such as physical requirements (linear shrinkage and moisture content, compressive strength, water absorption), minimum face-shell and web thickness and permissible dimension in variation and visual defects as defined in Table 2.3 and 2.4 above.

2.3. Marble

2.3.1. Marble 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, in the 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 [15].

2.3.2. Geological Formation of Marble

Marble is a metamorphic rock produced from limestone by pressure and heat in the earth crust due to a geological process. 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 into specific areas within the rock [16].

The pressure and heat in the earth’s crust cause limestone to change in texture and makeup. This process is called recrystallization. Fossilized materials in the limestone, along with its original carbonate minerals, re-crystallize and form large, coarse grains of calcite [17].

Impurities present in limestone during the re-crystallization period affect the mineral composition of marble which is formed [18]. 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 [16].

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 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 may result in the formation of hematite and magnetite [18].

2.3.3. Chemical and Physical Properties of Marble.

2.3.3.1. Chemical Properties of Marble.

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, Mn, and FeS_2 are the major chemical impurities associated with marble [18].

2.3.3.2. Physical Properties of Marble

Physically, marble is re-crystallized hard, compact, fine to very fine grained metamorphosed rocks capable of taking shining polish [18].

All limestones are crystalline but with varying crystal sizes and crystal arrangements [19].

Table 2.9: Typical physical properties of marble and limestone [18]

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

2.3.4. Uses of Marble

Colorless or light colored marble is 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 the 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 an 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 resistant [20]. 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, a 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 [21]. It is also a major input in the construction industry as in the production of cement, production of dimensional and non-dimensional stone, as aggregate in the road and concrete construction.

2.3.5. Marble 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) [22].

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 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 [22]. 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 lagoonal facies of Agula formation consisting of black shale, marl, and claystone with beds of limestone gypsum and dolomite in Mekale area, Tigray [22].

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 detrital 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 interbreeds of shale and gypsum particularly on the eastern extreme of Ogaden basin [22].

2.3.6. Marble Processing in the Ethiopian Marble Processing Enterprise

2.3.6.1. Historical Background

Italian investors primarily established the Ethiopian marble processing enterprise. 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 [23].

In 1950s 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 the public uprising in the country, the country’s economic systems were changed to command economy; “Nationalization” of Private Enterprises took place, as a result, these three Private Enterprises were nationalized by Proclamation. The three branches were incorporated 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 [23].

After the overthrow of the "Derg" regime, the Transitional Government of Ethiopia has reorganized the industry, as "The Ethiopian Marble Processing Enterprise". The Enterprise has three branches namely Gullelie, Bole and Nifas silk [23].

Currently, there are more than fourteen marble processing plants in Ethiopia located in different towns. Namely, Bekele Berhane Wondim, Berta Construction PLC, Ethiopian Marble processing Enterprise, Rift valley Gemstones Import and Export, Saba Dimensional Stones PLC, Tis Abay International PLC, Anteneh Worku Hiruy, Kara Marble Processing Enterprise. Assae Marble PLC, D.M.C Marble Plc, Ethiopian Marble Industry, Negat United Construction, and Sam Marble Industry [25].

2.3.6.2. 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 and from Benshangul Gumuz National Regional State a place known as "Enkonti", "Mora" and Mankush. The Enterprise produces different types of marble block from these quarry sites. The colour of the marble from these quarries varies, example Enkunti marble is white gray, and white, while "Mankush" marble has multi-colour, and rose, "Mora" marble mainly has a white colour [20].

2.4 Fine filler in concrete

Micro fines are materials 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 [25].

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 number of micro fines can lead to a reduction in workability of fresh concrete [25]. 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 [25].

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. [26].

2.5. Limestone filler in concrete

Limestone is made up of varying proportions of chemicals such as calcium carbonate ($CaCO_3$), Magnesium carbonate ($MgCO_3$), Silica (SiO_2), Alumina (Al_2O_3), Iron oxide (Fe_2O_3), Sulphate (SO_3), and Phosphors (P_2O_5) with calcium and magnesium carbonate being the two major components. Limestone is the most common form of calcium carbonate which is used extensively for the manufacture of cement. Cement in different types are made mainly by calcining a mixture of about 75% limestone and 25% clay to form a calcium silicate clinker which is then ground and mixed with a small amount of gypsum [27].

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. Traditional use of Calcium carbonate originates from France and has been in use for more than 25years [28].

In Europe, a number of countries allowed different percentages of limestone prior to the adoption of EN 197-1. 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). In addition, the inclusion of 5% of filler material that can be calcareous is accepted in all cement. 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 [29].

2.6 Some previous studies of using marble waste as filler in concrete

Marble powder as raw material to cement production was studied by National Council for cement and building material, Bombay [30]; 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 [31], 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 an increment of the percentage of cement by marble powder. It was studied by Valeria Carinaldesi & et al [32] that a mixture made of water, marble powder and hydrated lime $(CaOH)_2$ and cured in the sealed air-free environment, was not able to harden after 28 days of observation which implies that marble powder is not pozzolanic.

Abrar Awol in 2009 conducted research using marble waste in cement and concrete production and it was reported that increasing percentage of addition of marble waste to Ordinary Portland cement beyond 5%, in concrete production, results in a reduction of compressive strength and slump. But other properties of marble waste blended cement such as consistency, setting times, insoluble residue, sulfate residue and soundness remain within the acceptable limits of different standards [5].

2.7 Summary of literature review

The major by-product in the construction industry is marble waste, which is produced in significant amounts in different countries. Marble blocks are cut into smaller blocks in order to give the required smooth shape. During the cutting and polishing processes about 30% marble results in the dust, mainly composed of SiO_2, Al_2O_3, Fe_2O_3, and CaO, with some other minor constituents.

Masonry is the assemblage of building units joined with the help of cementitious material or any accepted joining material to perform the required function. The hollow concrete block is an alternative wall and floor making the material in building construction. Most hollow concrete blocks have one or more hollow cavity manufactured from a zero slump mixture of Portland cement, aggregates, water and sometimes admixtures. Hollow concrete blocks used for wall construction classified as load bearing and non-load bearing depends on their structural function.

The literature review addresses, hollow concrete block production, physical requirements like; -dimension and tolerance, density, compressive strength, water absorption, drying shrinkage, moisture content, a sampling of hollow concrete block criteria, chemical and physical property of marble and some previous studies of using marble waste as a filler in concrete.

Among the materials in use for the production of the hollow concrete block, cement is the most expensive material. In addition, the production of it is one of the environmentally unfriendly processes due to the release of CO_2 gases to the atmosphere. Most common blending materials used in cement production added in plant or sites are industrial wastes. This is because recycling of industrial wastes as blending materials has technical, economic and environmental benefits besides the reduction of CO_2 gas emission from cement production. Marble waste powder, which is a by-product of marble processing factory, was studied by many researchers for its use in concrete as a cement replacing material. Most of the researchers showed positive results and benefits [5].

Currently, there are more than fourteen marble processing plants in Ethiopia located in different towns. In Ethiopia, 3,365,615.00 metric square of marble commodities were produced from the year 2009 to 2013 which implies that 30% of this mineral was lost as waste[8]. Currently the amount of loss as waste is increasing as more other companies joined the industry than before. In addition to the loss, disposal of this waste material will cause different environmental problems like - 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. 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. When dumped along a catchment area of natural rainwater, it results in contamination of over groundwater reservoir and causes drainage problem. Thus, checking the feasibility of the marble byproduct powder or dust which is left as a waste in marble factories for using it as a partial cement replacement material in hollow concrete blocks production is the aim of this thesis.

CHAPTER THREE

METHODOLOGY AND MATERIALS USED IN THE RESEARCH

3.1 General

The materials used for the investigation are described with respect to their sources and relevant physical and chemical properties. All laboratory investigations on the produced HCB used in studying the properties of marble waste powder blended cement are carried out in Addis Ababa Institute of Technology University, School of Civil and Environmental Engineering construction material laboratory and Kality construction material production factory laboratory; whereas the chemical composition of waste marble dust is studied in Ethiopian Geological Survey. For studying the effects of marble waste powder on the properties of hollow concrete blocks, Dangote PPC with 32.5R grade cement, waste marble dust, pumice, sand, 01 aggregates and potable water were used.

3.2 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 textbooks, 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. Alternative data collection methods such as experiments like conducting physical tests such as compressive strength at the different age of production, water absorption capacity, density, specific gravity, a chemical tests like complete silicate analysis and pH value were conducted, observations and archival records are examined and used when proved suitable. To conduct a laboratory test 288 blocks were produced. Seventy-two (72 pieces) of them were produced without replacing cement by marble dust or they control analysis for the experimental study. The remaining number of blocks were produced by replacing cement by 10%, 20% and 30% of marble powder or dust. Compressive strength tests were carried out at the age of 7, 14, 21 and 28 days. Water absorption and density test were done at the age of 14 and 28 days.

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

Testing procedure initially started by producing 288 samples of hollow concrete blocks with partial replacement of cement by marble waste, which was produced in Akaki Kality construction material manufacturing factory, were visually inspected and were then prepared for laboratory tests like density, water absorption, and compressive strength tests. For compressive strength tests, the contact surfaces of the blocks with the testing machine were made plane by capping with 1:1 mortar of 2 to 3mm thickness. The samples were positioned in the testing machine such that the load is applied in the same direction as in service and the load is increased at the rate of 0.2 to 0.5N/mm^{2}s until the sample breaks. It is worth noting that all the hollow concrete block samples produced have two intermediate webs in the middle

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

3.3 Marble waste powder

The marble waste was originally 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 sunlight for more than 20 days until it is dry. A sample of waste marble dust was submitted to Geological Survey of Ethiopia; Geoscience Laboratory Center and pH value of sample and mineral composition of waste marble dust was determined by complete silicate analysis. Fineness of the sample was determined in Addis Ababa University Institute of technology chemical laboratory, by using Blaine air-permeability test. The test results are shown in Table 3.2 and 3.3 below. To compare chemical composition of the marble waste sample used for the research with researches done before using percentage by weight, the chemical composition of waste marble dust sample used by Abrar Awol is shown in Table 3.1.

Table 3.1 Chemical composition of waste marble dust [5]

Roll No.	Chemical Composition	Percentage by weight
1	SiO_2	0.62
2	Al_2O_3	0.16
3	Fe_2O_3	0.10
4	CaO	54.91
5	MgO	0.8
6	LOI	43.25
7	$CaCO_3$	98

The suitability of marble dust or powder was investigated from its chemical and mineralogical compositions which are the major properties responsible for the quality of cement. The European standard EN 197, for limestone to be used as additives or as main constituent filler in cement requirements was considered.

Laboratory test results indicated that, the $CaCO_3$ content was 95.74% which is greater than the standard requirement (75%) as given by EN 197.

Table 3.2 The chemical composition of marble dust using complete silicate analysis [this research data]

Roll No.	Chemical Composition	Test result of Limestone powder percentage by weight (%)	Standard used by the Mugher cement Factory (%) [27]
1	SiO_2	<0.01	≤5.0
2	Al_2O_3	2.41	≤1.50
3	Fe_2O_3	<0.01	≤0.80
4	CaO	55.24	≥50.0
5	MgO	1.10	≤0.80
6	Na_2O	0.01	≤0.30
7	K_2O	0.01	≤0.30
8	LOI	39.77	≥40.0
9	$CaCO_3$	95.74	≥90.0

Comparing the test results shown in Table 3.2 with EN 197-1 standard, and with past investigators report, the waste marble dust from Kara marble processing factory source is suitable for utilization as addition to cement under controlled and specified cement quality standards.

The potential of hydrogen or pH value is a figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid and higher values are more alkaline. The pH is equal to ($-\log_{10}c$, where c is the hydrogen ion concentration in moles per liter). pH is a critical factor in the chemistry of concrete. Constituents of concrete like Portland cement, the "binding" component in concrete, aggregates, and water has a pH value approaching 11, which is alkaline. pH value of waste marble dust used as a partial replacement of cement in hollow concrete block production is shown in Table 3.3 below.

Table 3.3 pH value of the sample.

Rol. No.	Sample	pH value
1	Marble waste or dust	9.32

3.3.1 Fineness

Fineness is usually measured by the Blaine air-permeability test that indirectly measures the surface area of the cement particles per unit mass. Cement with finer particles has more surface area in m^2 per kg of cement.

Blaine's air permeability apparatus consists essentially of a means of drawing a definite quantity of air through a prepared bed of cement of definite porosity. The fineness is expressed as a total surface area in square centimeters per gram [11].

Specific surface values are calculated in accordance with the following equation [Eq. 3.1]:

$$S = \frac{Ss * \sqrt{T}}{\sqrt{Ts}} \qquad \text{Eq. 3.1}$$

where:

S = is the specific surface of the test sample,

Ss = is the specific surface of the standard sample used in calibration of the apparatus. Ss=3774cm^2/gm

T = is measured the time interval of manometer drop for the test sample

Ts = is measured time interval of manometer drop for the standard sample used in calibration of the apparatus, Ts=29.77sec. [33]

It is a general practice to describe the fineness of cement by a single parameter, the specific surface area. Although cement of quite different particle size distributions might have the same specific surface area, this is still considered to be the most useful measure of cement fineness. The air permeability method of determining the specific surface is based on the relationship between the surface area of the particles in a porous bed and the rate of fluid flow through the bed.

The rate of hydration increases with increasing fineness. This leads to both higher rate of strength gain and a higher rate of evolution of heat. Since hydration takes place at the surface of the cement particles, and further hydration is hindered by the formation of the reaction products, finer particles will be more completely hydrated than coarser particles. Larger cement particles probably never hydrate completely. Increasing fineness tends to decrease the amount of bleeding, but at high fineness, the amount of water required for workability for non-air entrained concrete is increased, which results in increased drying shrinkage. Table 3.4 shows fineness of both marble waste powder and 32.5R Dangote PPC cement used for the research. Cement used for test is finer than marble waste dust.
According to the Ethiopian Standard, marble waste powder fineness is above the minimum limit. The standard states Ordinary Portland Cement shall have a specific surface area of not less than 2250 cm^2/g.

Table 3.4. Fineness using Blaine fineness

Rol No.	Physical Property	Time (Sec)	Blaine Fineness (cm^2/gm)
1	Marble waste	30.46	3817.49
2	32.5R Dangote PPC cement	35.19	4103.19

3.4 Water

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

3.5 Cement

For studying the effects of marble waste powder on the properties of hollow concrete production, Dangote PPC with 32.5R was used. That is, for all concrete specimens cast for the investigation, cement of Dangote PPC, which was manufactured according to Ethiopian standard ES-1177-1-2005 and European standard EN-197-1-2000, was used. Its fineness as measured in the lab, by Blaine, was 4103.19 cm^2/g.

3.6. Aggregates

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

3.6.1. 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 beside decreasing the quality of concrete. Accordingly, the sand for the experiment was tested for silt content and was found to have 4.71% silt content. This is below the maximum value recommended by Ethiopian standard. Therefore, the sand, used in all tests, was not washed.

3.6.2. 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.
Sieve Analysis is a procedure for the determination of the particle size distribution of aggregates using a series of square or round openings starting with the largest. It is used to determine the grading or aggregates and the fineness modulus, an index to the fineness and coarseness and uniformity of aggregates. It is after this analysis is carried out that aggregates are described as well graded, poorly graded, uniformly graded, gap graded, etc. Each of the above aggregate categories has a close association with a range of quality of concrete produced using the aggregate.

According to ES 596:2001 Lightweight, normal weight or a combination of both type of aggregates shall be used conforming to ES 412:2000 and ES 81:1990 respectively.

A combined grading of the aggregates should be such as to provide a concrete masonry unit of the specified types. The grading should be controlled throughout the production process to conform to the requirements. The aggregate should be acceptable and should all pass through a sieve of the nominal aperture size of 9.5 mm. In addition, in case of the hollow concrete unit, the size of the aggregate should not exceed two-thirds of the thickness of the thinnest part of the shell or web of the unit. Therefore, fine aggregate and coarse aggregate with gradation satisfying the grading requirement of Ethiopian standard were used throughout the experiment. The gradation of fine and coarse aggregates are shown in Table 3.5 to 3.7 below. The fineness modulus of fine aggregate used for the research is determined using equation [Eq 3.2] and the values of intermediate sieves are not included in the determination of Fineness Modulus.

$$F.M = \frac{\sum Cummulative\ coarser(\%)}{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad Eq.\ 3.2$$

where:

F.M = the fineness modulus of the aggregate,

Table 3.5. Gradation of fine aggregate used for the test.

Sieve size	Weight retained (gm)	Percentage retained (%)	Cumulative retained (%)	Cumulative passing (%)
9.5mm	0	0	0	100
4.75mm	5	0.25	0.25	99.75
2.36mm	12	0.6	0.85	99.15
1.18mm	210	10.5	11.35	88.65
300μ	570	28.5	99.85	60.15
150μ	1108	55.4	95.25	4.75
75μ	80	4.0	99.25	0.75
pan	15	0.75	100	0.0
			Total	246.8
			FM=	246.8/100=2.47

The grading or particle size distribution of coarse aggregate is within the limits specified for aggregates satisfying Ethiopian standards for 10mm coarse aggregate. Pumice size distribution is consistent from sieve size 25 mm to 9.5 mm on its limit except the sieve size

4.75 mm which is greater than ten percent. The test is done in accordance with ASTM C 136. The distributions are shown in Table 3.6 and 3.7 below.

Table 3.6. Gradation of coarse aggregate (01 aggregate) used for the test.

Sieve size (mm)	Weight retained (gm)	Percentage retained (%)	Cumulative retained (%)	Cumulative passing (%)
12.5	0	0	0	100
9.5	380	6.65	6.65	93.35
4.75	2049	35.89	42.54	57.46
2.36	2103	36.83	79.37	20.63
pan	1178	20.63	100	0.0
Total	5710			

Distribution of pumice on sieve size from 25 mm to 9.5 mm is consistent on its limit except the sieve size 4.75 mm which is greater than ten percent.

Table 3.7. Gradation of coarse aggregate (Pumice) used for test.

Sieve size (mm)	Weight retained (gm)	Percentage retained (%)	Cumulative retained (%)	Cumulative passing (%)
25	0	0	0	100
19	145	3.68	3.68	96.32
12.5	1265	32.11	35.79	64.21
9.5	1160	29.44	65.23	34.77
4.75	760	19.29	84.52	15.48
pan	610	15.48	100	0.0
Total	3940			

CHAPTER FOUR

EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 Experimental program

The main target of this study is to produce HCB made with partial replacement of marble waste dust or powder and then to characterize its properties, especially the mechanical properties in the hardened state. A waste marble dust having a fineness of 3817.49cm^2/g from marble processing factory was used. Three class of HCB, namely Class A, Class B and Class C were produced incorporating four different volume fractions, which are 30%, 20%, 10% and 0%. Each volume fraction enclosed three different classes of HCB. The replacement rate of 0% was used as control mix.

As already discussed in the other chapters, the main factors controlling the mechanical performance of the obtained HCB are the properties of the ingredient, as well as the bond between them. For this reason, investigation of the properties of the constituents material and preliminary characterization of their mechanical property was performed. The performance of waste dust blended HCB were evaluated in order to check the effect of waste marble dust on produced hollow concrete blocks. Thereafter, the compressive strength in the hardened state at 7th, 14th, 21st and 28th day and water absorption and density at 14th and 21st day were evaluated for each mix and class, varying the volume fraction of cement by waste marble dust.

To achieve these targets, two major experiments were designed. The first experiment was done to determine properties of HCB ingredients, the chemical composition of marble powder, pH (potential of hydrogen) value of marble powder, fineness of marble powder, the gradation of aggregates, and silt content of fine aggregate was determined.

Following experiment one, another experiment, experiment two was performed to determine the effects of replacing part of cement with marble waste powder on a hollow concrete block compressive strength, density, and water absorption.

In this section, the test results on the physical and chemical properties of marble waste powder, and the test results on the performance of hollow concrete blocks made with marble waste blended cement, are presented, analyzed and discussed.

4.2 Mix design 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 objective of producing concrete of certain minimum strength and durability as economically as possible.

Too little water causes the mix to be friable, while too much water causes difficulty in the immediate withdrawal of the mold. Because of this controlling water to cement ratio of the mix in between 0.3 to 0.4 is very important. the quantity of water required for one cubic meter of mix is calculated using the following equation [Eq.4.1]

$$water(kg) = 0.4 * cement(kg) \qquad \text{Eq. 4.1}$$

where:

0.4 = is water to cement ratio used to mix the samples

For this experiment, mix design proportion is done for three classes of hollow concrete blocks namely: - Class A, Class B, and Class C hollow concrete blocks. The proportion of the materials as per the design is given in Table 4.1 below.

Table 4.1 Mix proportion of materials for the production of class A, Class B, and Class C HCB.

HCB Class	Size of Blocks			Number of blocks produced per 50kg of cement	Ingredient per 50kg of Cement in (box size 50x40x20)cm			water per 50kg of Cement in liter
	H	W	L		Sand	Aggregate “01”	Pumice	
A	20	20	40	20	2	4	1	20
B	20	20	40	26	2	4	3	20
C	20	20	40	32	2	5	4	20

In the research the theoretical mix design, designed by Akaki Kality construction materials production factory, for hollow concrete block is used, trial mixes were prepared and tested for compressive strength at 7^{th}, 14^{th}, 21^{st} and 28^{th} day. The results are shown in the following tables.

Table 4.2: Proportion of materials for trial mixes for 10% replacement.

HCB Class	Size of Blocks			Ingredient for 45kg of Cement and 5kg marble dust in (m^3)			Number of blocks produced per 50 kg of cement	Ingredient for 45 kg of Cement and 5kg marble dust in (box size 50x40x20)cm		
	H	W	L	Sand	Aggregate 01	Pumice		Sand	Aggregate 01	Pumice
A	20	20	40	0.08	0.16	0.04	20	2	4	1
B	20	20	40	0.08	0.16	0.12	26	2	4	3
C	20	20	40	0.08	0.20	0.16	32	2	5	4

Proportion of materials for trial mixes of 0%, 10%, 20%, and 30% replacement percent are the same for aggregates and water. Cement replacement in weight is shown in Table 4.3 below.

Table 4.3: Proportion of cement and marble for trial mixes of 0%, 10%, 20%, and 30% replacement for all classes of HCB.

Replacement in Percent [%]	Dangote PPC with 32.5R grade cement [kg]	Marble waste powder [kg]
0	50	0
10	45	5
20	40	10
30	35	15

4.3. Curing

After the hollow concrete block was cast, it was left for 10 minutes in the open air. Then it was trimmed and, finished on the panel. 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. GTZ low-cost housing manual Volume I specify the extruded hollow concrete block shall remain for 24 hours on a wooden pallet then it is being cured covered by a plastic sheet to enhance the curing process and preventing the water from evaporation.

The blocks shall be stocked on a clean and level platform free from earth or other impurities during the curing process and shall be stocked in honeycomb fashion with voids horizontal to facilitate through the passage of air until test period.

4.4 Compressive strength test

As discussed above in the literature review strength of hollow concrete block is closely related to the specimen size and shape, method of pore formation, direction of loading, age, applied load, rate of loading, degree of compaction, and cement content characteristic of its ingredients used, method of curing, size and number of holes created. Both hollow structure of the air holes and mechanical condition of the pore shells have a great influence on the compressive strength of the hollow concrete block. It has also been found that a reduction in density due to the formation of holes will result in a significant drop in strength. All the trials were 20x20x40cm size hollow concrete block with three holes in a single block.

For compressive strength tests, the contact surfaces of the blocks with the testing machine were made plane by capping with 1:1 mortar of 2 to 3mm thickness. The samples were positioned in the testing machine such that the load is applied in the same direction as in service and the load is increased at the rate of 0.2 to 0.5N/mm^{2}s until the sample breaks.

For observing the performance changes due to the substitution of part of cement by marble waste powder in hollow concrete block production, three classes of hollow concrete blocks, class A, class B and class C were prepared and tested for compressive strength at 7, 14, 21 and 28 days.
The value of each hollow concrete blocks' compressive strength is calculated using the following equation [Eq. 4.2].

$$Compressive\ strength\ blocks = \frac{F}{A} \qquad \text{Eq. 4.2}$$

where:

F = Applied load on blocks in kN

A_{total} = 20cm*40cm=800cm^2

A_{holes} = 2*(14*10)+(14*6)+2*(1*14) = 392 cm^2

A_{net} = A_{total} - A_{holes}=800 cm^2 - 392 cm^2 = 408 cm^2

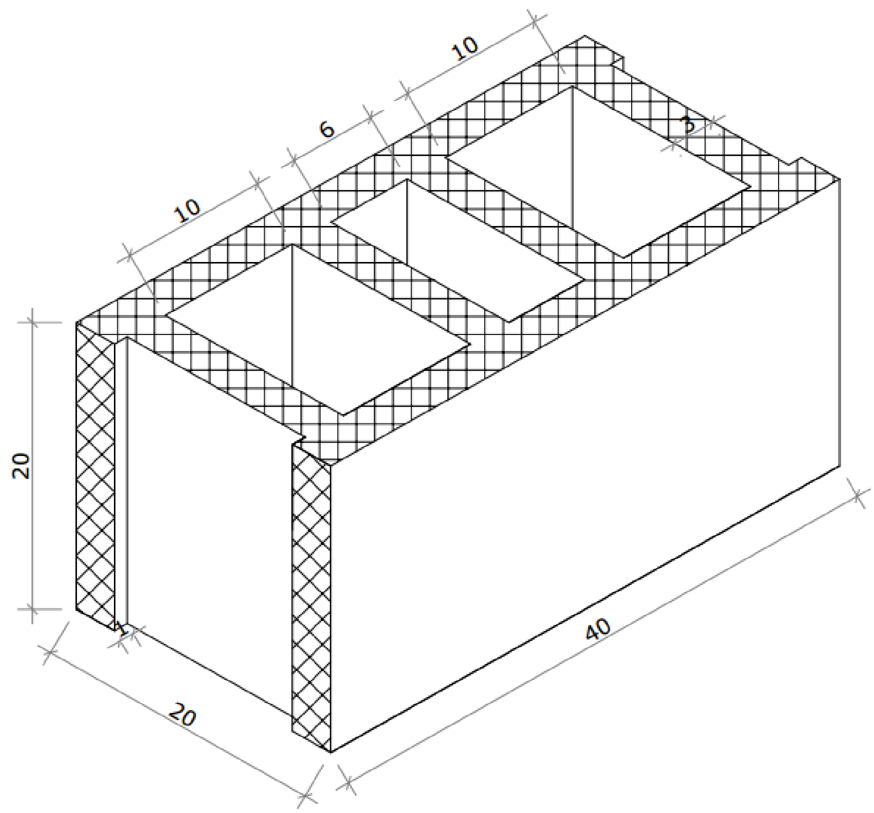

Fig 4.1: Dimension of a typical hollow concrete block used for the research.

For observing the changes due to the substitution of part of cement by marble waste powder in hollow concrete block production, three classes of hollow concrete blocks with size 20x20x40 cm prepared and tested for compressive strength at 7, 14, 21 and 28 days. The test results for all samples are presented in the Annex A. However, for the purpose of discussion, the summarized test results are presented in Tables from 4.4 to 4.7 below according to the classes of the blocks and replacement rates.

In this experiment, in all cases, i.e. from 0 to 30% substitution of cement by marble waste powder for all classes of size 20x20x40 cm hollow concrete blocks specimens, as shown in Table 4.4 to 4.7 show that the seventh, fourteenth, twenty-first and twenty-eighth days' compressive strength with marble waste powder is less than that of the corresponding control specimens. The reduction of the strength decreased with increasing percentage of marble waste powder in all cases except for class B that remains slightly constant in all trials at the twenty first day.

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

The latter age strengths of hollow concrete blocks specimens at 28 days for all percentage substitution of marble by cement in all classes are not the same as that of the corresponding control specimens, all result decreases. But beyond 20% substitution range for class B HCB specimens at the fourteen days' strengths increase with the addition of marble powder than 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. Reduction increment with the increment of percentage of marble waste powder, attributes to the replacement of Portland pozzolana 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.

The compressive strength of all specimens at 28 days fulfills the minimum compressive strength for hollow concrete blocks set by Ethiopian standard [ES 596:2001] up to 30% substitution for all classes.

Table 4.4: - Seven days' average compressive strengths of control and trial mix for class A, B and C size 20x20x40 hollow concrete blocks.

Class of HCB	Percent replacement [%]	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
A	0	7	20	20	40	21.07	258,996	6.35
	10	7	20	20	40	20.66	195,342	4.79
	20	7	20	20	40	20.67	195,342	5.54
	30	7	20	20	40	20.60	159,219	3.90
B	0	7	20	20	40	22.41	208,029	5.10
	10	7	20	20	40	20.00	178,308	4.37
	20	7	20	20	40	21.59	161,325	3.95
	30	7	20	20	40	22.27	137,905	3.38
C	0	7	20	20	40	20.63	211,782	5.19
	10	7	20	20	40	20.47	184,439	4.52
	20	7	20	20	40	20.37	167,727	4.11
	30	7	20	20	40	21.39	148,621	3.64

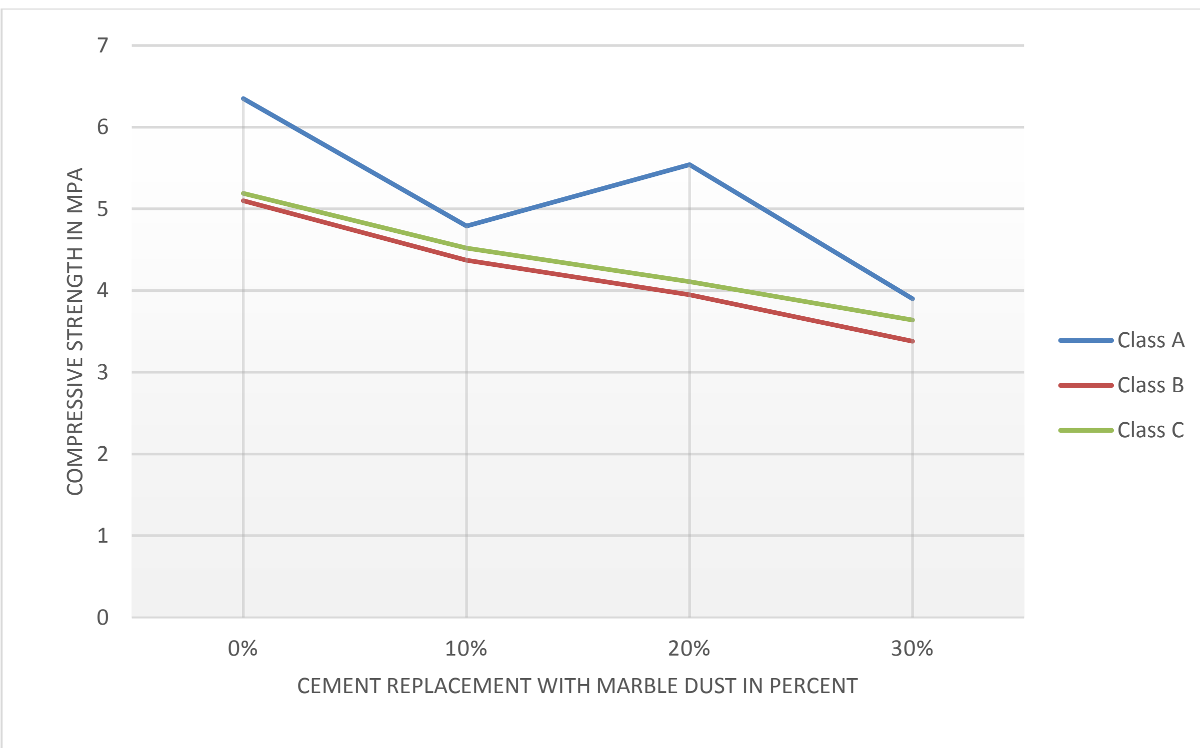

Fig 4.2: Seven days' average compressive strengths of control and trial mix for class A, B, and C size 20x20x40 hollow concrete blocks.

Table 4.5: - Fourteen days' average compressive strengths of control and trial mix for class A, B and C size 20x20x40 hollow concrete blocks.

Class of HCB	Percent replacement [%]	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength MPa]
			H	W	L			
A	0	14	20	20	40	20.69	309,538	7.59
	10	14	20	20	40	19.81	292,963	7.18
	20	14	20	20	40	20.40	286,526	7.02
	30	14	20	20	40	19.83	239,499	5.87
B	0	14	20	20	40	20.32	250,674	6.14
	10	14	20	20	40	19.14	220,783	5.41
	20	14	20	20	40	20.24	231,398	5.67
	30	14	20	20	40	20.51	227,152	5.57
C	0	14	20	20	40	20.8	228,001	5.59
	10	14	20	20	40	19.90	227,577	5.58
	20	14	20	20	40	19.72	225,029	5.52
	30	14	20	20	40	19.40	198,705	4.87

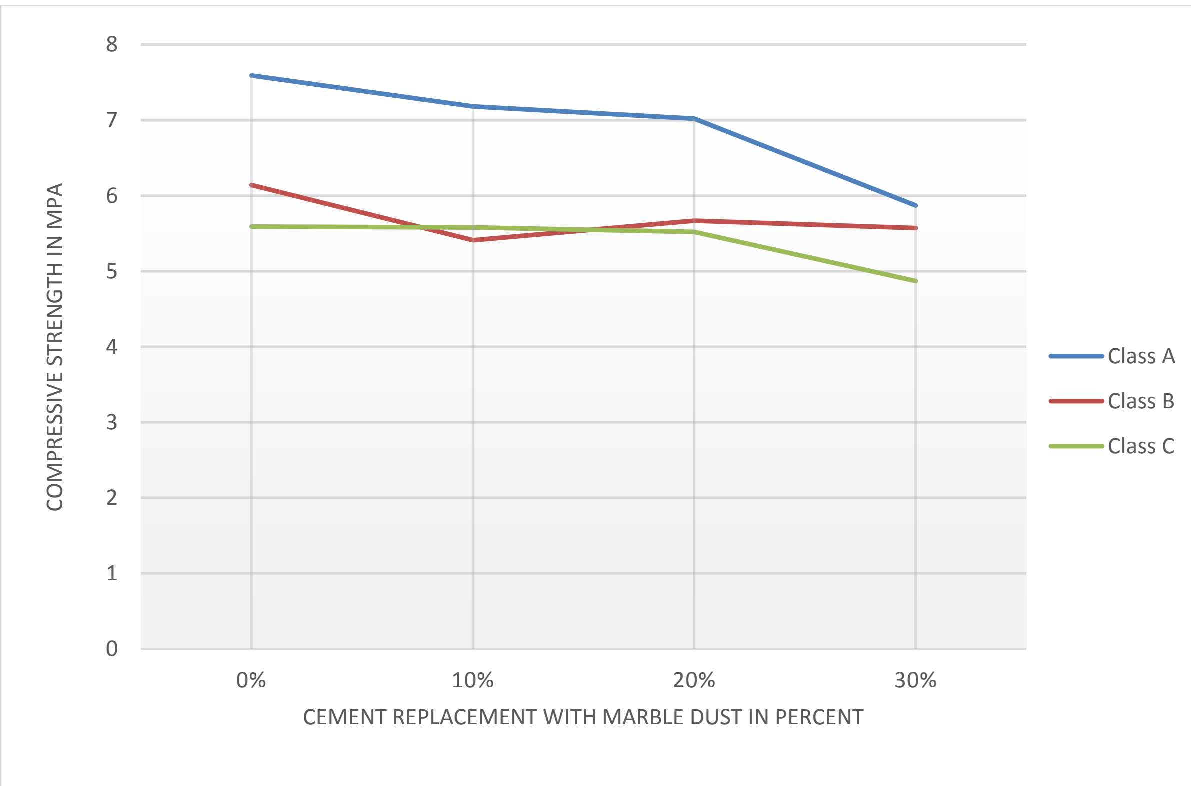

Fig 4.3: Fourteen days' average compressive strengths of control and trial mix for class A, B, and C size 20x20x40 hollow concrete blocks.

Table 4.6: Twenty-one days' average compressive strengths of control and trial mix for class A, B, and C size 20x20x40 hollow concrete blocks

Class of HCB	Percent replacement [%]	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [KN]	Compressive strength MPa]
			H	W	L			
A	0	21	20	20	40	19.98	335,421	8.22
	10	21	20	20	40	19.94	292,963	7.18
	20	21	20	20	40	20.18	284,471	6.97
	30	21	20	20	40	17.71	239,907	5.88
B	0	21	20	20	40	20.04	254,580	6.24
	10	21	20	20	40	18.52	220,614	5.41
	20	21	20	20	40	19.92	220,783	5.41
	30	21	20	20	40	20.01	208,895	5.12
C	0	21	20	20	40	19.71	249,825	6.12
	10	21	20	20	40	20.37	266,893	6.54
	20	21	20	20	40	19.11	225,029	5.52
	30	21	20	20	40	19.85	210,186	5.15

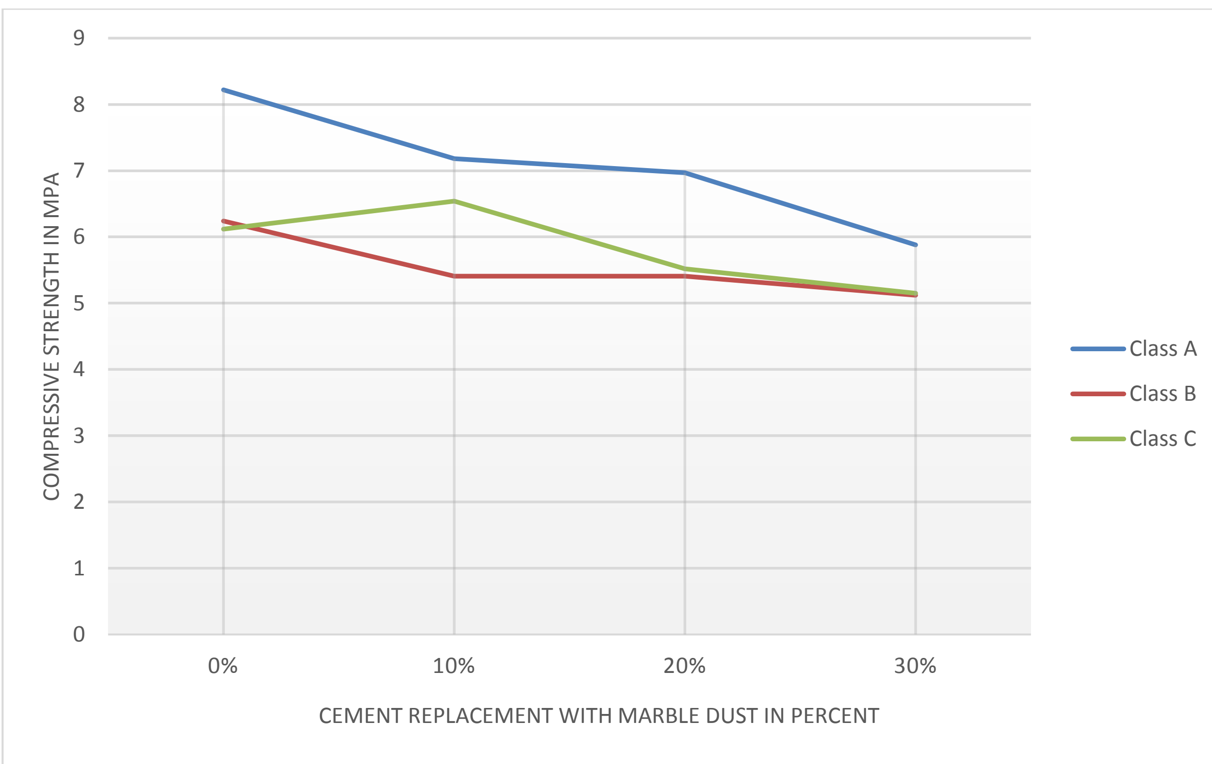

Fig 4.4: Twenty-one days' average compressive strengths of control and trial mix for class A, B, and C size 20x20x40 hollow concrete blocks.

Table 4.7: -Twenty-eight days' average compressive strengths of control and trial mix for class A, B, and C size 20x20x40 hollow concrete blocks.

Class of HCB	Percent replacement [%]	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
A	0	28	20	20	40	19.08	444,199	10.89
	10	28	20	20	40	19.58	367,265	9.00
	20	28	20	20	40	19.42	303,577	7.44
	30	28	20	20	40	19.36	248,381	6.09
B	0	28	20	20	40	19.61	374,347	9.18
	10	28	20	20	40	18.65	261,883	6.42
	20	28	20	20	40	20.41	231,823	5.68
	30	28	20	20	40	19.37	200,828	4.92
C	0	28	20	20	40	19.68	316,315	7.75
	10	28	20	20	40	19.15	250,504	6.14
	20	28	20	20	40	19.80	235,644	5.78
	30	28	20	20	40	19.54	218,660	5.36

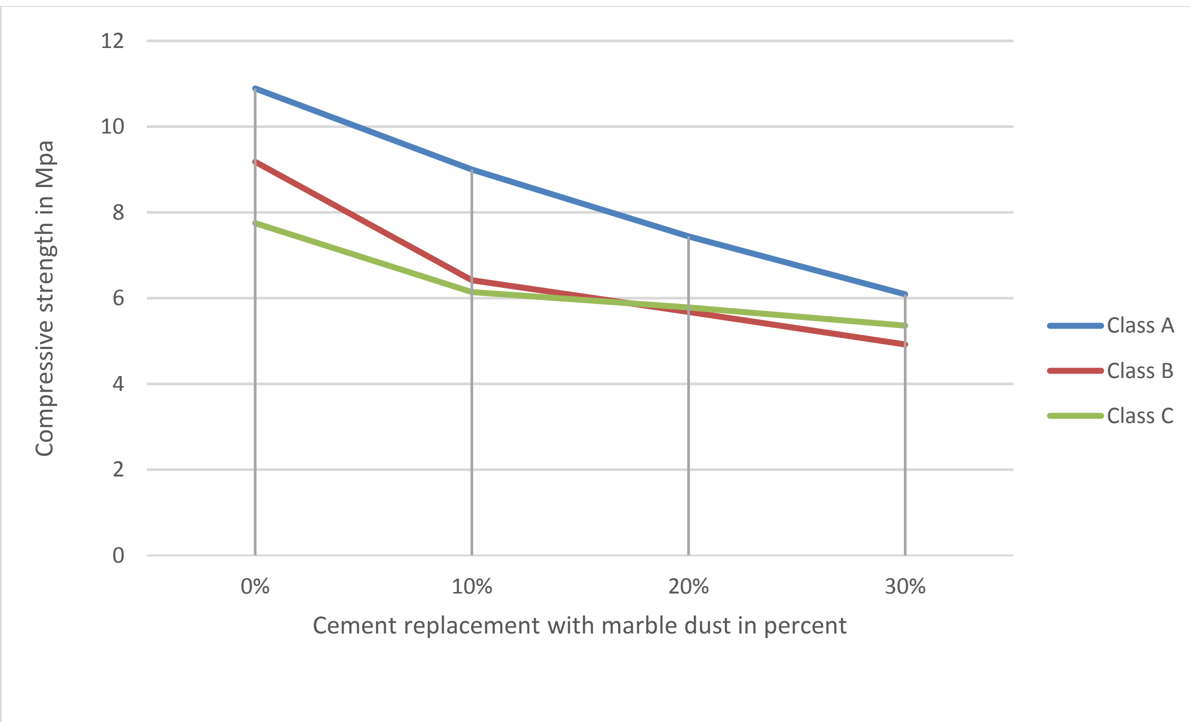

Fig 4.5: Twenty-eight days' average compressive strengths of control and trial mix for class A, B, and C size 20x20x40 hollow concrete blocks.

4.5 Water absorption and Density test

For assessing changes due to the addition of marble waste in cement in Hollow concrete block production, water absorption and density test were conducted.

Water absorption was determined from six full-size units by completely immersing them in water at room temperature for 24 hours. After 24 hours they were removed from the water and allowed to drain for one minute. For observing the changes due to the substitution of part of cement by marble waste powder in hollow concrete block production, three classes of hollow concrete blocks with size 20x20x40 cm are prepared and tested for water permeability and density at 21^{st} day. The results are shown in Table 4.8 and 4.9.

4.5.1. Absorption of HCB prepared by cement blended with marble waste powder

Ethiopian standard [ES 596:2001] specify water absorption 290kg/m^3 (25%) for load bearing hollow concrete block and 320kg/m^3 (30%) for non-load bearing hollow concrete block.

In this experiment, in all cases, i.e. from 0% to 30% substitution of cement by marble waste powder for all classes of size 20 cm x 20 cm x 40 cm hollow concrete block specimens, the test results in Table 4.8 shows that the twenty-first day’s water absorption with marble waste powder is less than that of the recommended value which is 25% for load bearing. The reduction of the water absorption decreased with increasing percentage of marble waste powder in all cases.
According to ES: 596:2001 absorption in kg/m^3 shall be calculated using the following equation [Eq.4.3].

$$Absorption = \frac{A-B}{A-C} * 1000 \ldots\ldots\ldots\ldots\ldots\ldots \quad Eq.\ 4.3$$

where:

A = Absorption, %= $\frac{A-B}{B}$*100

B = Dry mass of unit in kg, and

C = Suspended immersed mass of unit in kg

Table 4.8: - Average water absorption of control and trial mixes for class A, B and C size 20x20x40 hollow concrete blocks.

Class of HCB	Percent replacement [%]	Test age [days]	Dimension [cm]			Weight after removed from water and dried for one min.[kg] [A]	Weight before immersed into water [kg] [B]	Percent absorption $\frac{A-B}{B}*100$ [%]
			H	W	L			
A	0	21	20	20	40	19.87	18.6	6.83
	10	21	20	20	40	19.2	18.3	4.92
	20	21	20	20	40	18.75	17.9	4.75
	30	21	20	20	40	18.43	17.8	3.54
B	0	21	20	20	40	15.79	14.6	8.15
	10	21	20	20	40	15.36	14.3	7.41
	20	21	20	20	40	15.65	14.7	6.46
	30	21	20	20	40	14.58	13.9	4.89
C	0	21	20	20	40	15.52	14.5	7.03
	10	21	20	20	40	14.67	13.8	6.30
	20	21	20	20	40	14.3	13.6	5.15
	30	21	20	20	40	13.7	13.2	6.83

The result in Table 4.8 shows that reduction of the water absorption decreased with increasing percentage of marble waste powder in all cases or as the amount of Portland pozzolana cement in the mix is reduced the amount of water absorption gets decreasing. All the results of water absorption with marble waste powder is less than that of the recommended value which is 25% for load bearing according to Ethiopian standard ES: 596:2001.

4.5.2. The density of HCB prepared by cement blended with marble waste powder

The density of trials hollows concrete block was obtained after the casting process by taking six blocks taken after water absorption test and then dried to constant mass in a suitable oven heated to 105°C. After cooling the blocks to room temperature, the dimensions of each block was measured in centimeters and the net volume is computed in cubic centimeters. The blocks were then weighed in gram and the density of each block was calculated using the following equation [Eq. 4.4] and the result is shown in Table 4.9.

$$Density = \frac{mass\ of\ block\ in\ kg}{Net\ volume\ of\ speciemen\ in\ cm^3} x10^6\ kg/m^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ Eq.\ 4.4$$

where:

$V_{net} = A_{net} * h = 408\ cm^2 * 20\ cm = 8160\ cm^3$

Table 4.9: - Average density of control and trial mixes for class A, B and C size 20x20x40 hollow concrete blocks.

Class of HCB	Percent replacement [%]	Test age [days]	Dimension [cm]			Weight before oven dry [kg]	Weight after oven dry [kg]	The average dry density of produced block [kg/m³]
			H	W	L			
A	0	21	20	20	40	19.09	18.10	2218.14
	10	21	20	20	40	19.00	18.03	2209.56
	20	21	20	20	40	18.04	17.50	2144.61
	30	21	20	20	40	18.96	17.01	2084.56
B	0	21	20	20	40	14.58	14.20	1740.20
	10	21	20	20	40	14.95	14.00	1715.69
	20	21	20	20	40	14.71	13.79	1689.95
	30	21	20	20	40	13.6	12.67	1552.70
C	0	21	20	20	40	14.7	13.93	1707.11
	10	21	20	20	40	14.73	13.80	1691.18
	20	21	20	20	40	14.43	13.70	1678.92
	30	21	20	20	40	14.74	13.68	1676.47

For hollow concrete, low density is probably the most characteristic feature. This is due to the holes. In addition, it depends primarily on the aggregate density and the proportions of aggregate because the particle density of individual grading fraction can differ considerably and thus will affect the density of concrete. This property also influenced by the cement, water, and air contents. In this experiment, in all cases, i.e. from 0% to 30% substitution of cement by marble waste powder for all classes of size 20x20x40 cm hollow concrete block specimens, the test results, as shown in Table 4.9 show that the density of blocks decreases with replacement percent increases, this implies density of waste marble dust is less than ordinary Portland cement. All trials satisfy minimum density requirement set by Ethiopian standard and Indian standard

The total number of hollow concrete blocks produced for compressive strength, water absorption, and density test with size 20x20x40 is 288pcs of blocks, the detail is shown in the Appendices below, and they were prepared for compressive strength, water absorption, and density test.

4.6. Suitability of marble waste powder as a partial replacement of cement in HCB production

To check the suitability of the marble waste powder as a partial replacement of cement in HCB production, the research began by studying the physical and chemical properties of the marble waste powder.

As fineness affects replacement effect, the fineness of the powder was taken as main evaluation criteria for physical properties. From chemical composition point, the calcium carbonate and clay content limit set by EN 197-1:2000 for CEM II/B-P 32.5R PN cement was taken as evaluation criteria.

Physically, as tested in the laboratory, the fineness value of the marble waste powder which was 3817.49cm^2/g is comparable with the fineness of modern Portland cement (3000-5000cm^2/g). Chemical composition analysis of a sample of marble waste powder, as shown in Table 3.2, 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 CEM II/B-P 32.5R PN replacement. In addition, other chemicals in the waste powder are very small in percentage. From the EN 197-1 standard requirement of limestone for the cement production, the test results of the chemical composition of the marble waste powder, as shown in Table 3.2, ascertains the suitability of the waste powder for use as a partial replacement in cement.

4.7. Economic Benefit

4.7.1. For the Marble Waste Powder Producer

The producer of a waste will ensure environmental benefits as far as the waste is used. It is also expected that it can get more economic 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.

4.7.2. For the Construction Industry

One of the greatest environmental concerns in the construction industry is the production of cement which emits a large amount of CO_2 gas to the atmosphere. The amount of loss as waste is increasing as more other companies joined the industry than before. Recycling marble waste powder in substitution of cement also indirectly can reduce environmental problem related to cement production.

In this research work, detail cost break down and economic analysis was not worked out as the cost of cement depends on its user point location; but to give insight for cost benefits, the average cost of cement, and selling price of marble waste is presented below in Table 4.10.

Table 4.10: Average price of cement, and marble waste in Addis Ababa

S.No	Type of Material	Average Price per 100 kg (Birr)
1	Cement	230
2	Marble waste	15

Hollow concrete block production without partial replacement of cement is expensive than hollow concrete blocks with partially replaced cement hollow concrete blocks. As the replacement range increases the cost reduction increase by 9.35%. The calculated prices for cement and marble per 20 blocks for class A, per 26 blocks for class B and per 32 blocks for class C are shown in Table 4. 11 with their respective replacement percentage.

Table 4.11: Cost of cement, and marble waste in Addis Ababa per 20, 26, and 32 number of blocks for class A, B, and C.

Cost of cement and marble per 20 number of blocks for class A HCB							
Percent replacement [%]	Cement in kg	Marble to replace cement in kg	Cost of cement in Birr	Cost of marble in Birr	Total Birr	Cumulative difference in Birr	Cumulative difference in percent [%]
0	50	0	115.00	0.00	115.00		
10	45	5	103.50	0.75	104.25	10.75	9.35
20	40	10	92.00	1.50	93.50	21.50	18.70
30	35	15	80.50	2.25	82.75	32.25	28.04
Cost of cement and marble per 26 number of blocks for class B HCB							
0	50	0	115.00	0.00	115.00		
10	45	5	103.50	0.75	104.25	10.75	9.35
20	40	10	92.00	1.50	93.50	21.50	18.70
30	35	15	80.50	2.25	82.75	32.25	28.04
Cost of cement and marble per 32 number of blocks for class C HCB							
0	50	0	115.00	0.00	115.00		
10	45	5	103.50	0.75	104.25	10.75	9.35
20	40	10	92.00	1.50	93.50	21.50	18.70
30	35	15	80.50	2.25	82.75	32.25	28.04

The above Table 4.11 clearly show that using of marble waste in replacement of cement in Addis Ababa can play cost reduction in hollow concrete block production.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In this research, using of marble waste powder for the production of the hollow concrete block has been studied. The experimental works are carried out to evaluate the hardened properties of hollow concrete blocks. Based on results obtained by compressive strength of hollow concrete blocks, water absorption, and density, the following conclusions are drawn: -

1. Marble waste powder from the Kara Marble Processing Enterprise used for the study satisfies the chemical standard requirement for partial replacement of Portland pozzolana cement, and natural fineness of the marble waste is comparable with that of the fineness of Portland pozzolana cement to be used as a filler or as a partial replacement.

2. Increasing percentage of addition of marble waste to Portland pozzolana cement results in general compressive strength reduction than PPC cement. However, other properties of marble waste blended cement of hollow concrete blocks such as density and water absorption remain within the acceptable limits of Ethiopian standard.

3. Replacement at 10%, 20%, and 30% replacement ranges result in compressive strength reduction than that of 100% Portland pozzolana cement. However, the compressive strength of blended cement with 10 to 30% replacement ranges satisfy the minimum, compressive strength of hollow concrete block set by Ethiopian standard for class A, B and C hollow concrete blocks.

4. Replacement of cement by marble waste powder up to 30% improves water absorption property of the hollow concrete blocks. In addition, all trials satisfy minimum density requirement set by Ethiopian standard and Indian standard.

5. The marble waste up to 20% can replace cement in hollow concrete production with improvement of related to water permeability.

6. It is possible to save 9.35%, 18.70%, and 28.04% of cost per 50 kg of cement compared to hollow concrete block produced without replacement of cement, by addition of 10%, 20% and 30% of marble waste powder to cement respectively.

6.2 Recommendations

Our construction industries need to benefit from the using of wastes. Therefore, based on the investigation made the following recommendations are forwarded for studies for the purpose of future excellence.

1. Marble waste from Marble Processing Enterprise can be used in hollow concrete production as a partial replacement of cement. Nevertheless, currently, there is no hollow concrete block production Enterprises, which is near to the marble processing Enterprise, which makes using this by-product non-feasible cost wise. Therefore, the marble processing enterprise and hollow concrete blocks manufacturing enterprises should work together for further study and applications.

2. In this research, only compressive strength, density and water absorption using marble waste in hollow concrete block production are investigated; therefore, further investigations are required in the following areas.
    - Studies should be made by grinding marble waste powder together with cement using different fineness and types of cement.
    - Detail study of the durability of a hollow concrete block made by marble waste blended cement should be made.

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ANNEXES

ANNEXE A

COMPRESSIVE STRENGTH TEST RESULT

Table A.A.1: 7th days' compressive strengths of control and trial mixes for class A size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	7	20	20	40	20.34	286,543	7.02
	2	7	20	20	40	21.68	248,432	6.09
	3	7	20	20	40	21.20	242,013	5.93
	Mean						**258,996**	**6.35**
10%	1	7	20	20	40	21.01	222,957	5.46
	2	7	20	20	40	19.76	222,957	5.46
	3	7	20	20	40	21.22	140,113	3.43
	Mean						**195,342**	**4.79**
20%	1	7	20	20	40	20.88	178,325	4.37
	2	7	20	20	40	20.40	235,389	5.77
	3	7	20	20	40	20.76	216,538	5.31
	Mean						**210,084**	**5.54**
30%	1	7	20	20	40	19.86	178,325	4.37
	2	7	20	20	40	21.05	140,113	3.43
	3	7	20	20	40	20.90	159,219	3.90
	Mean						**159,219**	**3.90**

Table A.A.2: 7th days' compressive strengths of control and trial mixes for class B size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [mm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	7	20	20	40	25.05	159,168	3.90
	2	7	20	20	40	21.39	178,325	4.37
	3	7	20	20	40	20.80	286,594	7.02
	Mean						**208,029**	**5.10**
10%	1	7	20	20	40	19.82	184,694	4.53
	2	7	20	20	40	20.26	171,905	4.21
	3	7	20	20	40	19.94	178,325	4.37
	Mean						**178,308**	**4.37**
20%	1	7	20	20	40	21.54	146,481	3.59
	2	7	20	20	40	21.63	171,905	4.21
	3	7	20	20	40	21.59	165,588	4.06
	Mean						**161,325**	**3.95**
30%	1	7	20	20	40	21.64	178,325	4.37
	2	7	20	20	40	22.38	127,375	3.12
	3	7	20	20	40	22.79	108,014	2.65
	Mean						**137,905**	**3.38**

Table A.A.3: 7th days' compressive strengths of control and trial mixes for class C size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [kN]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	7	20	20	40	20.35	191,063	4.68
	2	7	20	20	40	20.85	208,895	5.12
	3	7	20	20	40	20.71	235,389	5.77
	Mean						**211,782**	**5.19**
10%	1	7	20	20	40	20.72	184,439	4.52
	2	7	20	20	40	20.54	184,439	4.52
	3	7	20	20	40	20.14	184,439	4.52
	Mean						**184,439**	**4.52**
20%	1	7	20	20	40	20.45	172,007	4.22
	2	7	20	20	40	19.96	178,325	4.37
	3	7	20	20	40	20.70	152,850	3.75
	Mean						**167,727**	**4.11**
30%	1	7	20	20	40	21.27	172,007	4.22
	2	7	20	20	40	21.47	114,638	2.81
	3	7	20	20	40	21.44	159,219	3.90
	Mean						**148,621**	**3.64**

Table A.A.4: 14th days' compressive strengths of control and trial mixes for class A size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	14	20	20	40	20.22	343,913	8.43
	2	14	20	20	40	20.43	299,382	7.34
	3	14	20	20	40	21.42	280,225	6.99
	Mean						**309,538**	**7.59**
10%	1	14	20	20	40	19.67	286,594	7.02
	2	14	20	20	40	20.43	312,069	7.65
	3	14	20	20	40	19.34	280,225	6.87
	Mean						**292,963**	**7.18**
20%	1	14	20	20	40	20.85	248,432	6.09
	2	14	20	20	40	19.81	324,552	7.95
	3	14	20	20	40	20.56	286,594	7.02
	Mean						**286,526**	**7.02**
30%	1	14	20	20	40	19.56	247,770	6.07
	2	14	20	20	40	21.29	247,770	6.07
	3	14	20	20	40	18.64	222,957	5.46
	Mean						**239,499**	**5.87**

Table A.A.5: 14th days' compressive strengths of control and trial mixes for class B size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	14	20	20	40	20.28	255,769	6.27
	2	14	20	20	40	20.60	238,446	5.84
	3	14	20	20	40	20.09	257,807	6.32
	Mean						**250,674**	**6.14**
10%	1	14	20	20	40	17.62	178,325	4.37
	2	14	20	20	40	20.82	280,225	6.87
	3	14	20	20	40	18.98	203,800	5.00
	Mean						**220,783**	**5.41**
20%	1	14	20	20	40	19.45	242,013	5.93
	2	14	20	20	40	20.46	216,538	5.31
	3	14	20	20	40	20.82	235,644	5.78
	Mean						**231,398**	**5.67**
30%	1	14	20	20	40	20.14	267,488	6.56
	2	14	20	20	40	20.77	235,644	5.78
	3	14	20	20	40	20.64	178,325	4.37
	Mean						**227,152**	**5.57**

Table A.A.6: 14th days' compressive strengths of control and trial mixes for class C size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	14	20	20	40	21.28	231,313	5.67
	2	14	20	20	40	21.16	235,644	5.78
	3	14	20	20	40	19.96	217,047	5.32
	Mean						**228,001**	**5.59**
10%	1	14	20	20	40	20.36	275,130	6.74
	2	14	20	20	40	19.12	203,800	5.00
	3	14	20	20	40	20.22	203,800	5.00
	Mean						**227,577**	**5.58**
20%	1	14	20	20	40	19.86	254,750	6.24
	2	14	20	20	40	19.08	191,063	4.68
	3	14	20	20	40	20.22	229,275	5.62
	Mean						**225,029**	**5.52**
30%	1	14	20	20	40	19.25	127,375	3.12
	2	14	20	20	40	19.89	203,800	5.00
	3	14	20	20	40	19.06	264,940	6.49
	Mean						**198,705**	**4.87**

Table A.A.7: 21st days' compressive strengths of control and trial mixes for class A size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	21	20	20	40	19.75	343,913	8.43
	2	21	20	20	40	20.26	382,125	9.37
	3	21	20	20	40	19.93	280,225	6.87
	Mean						**335,421**	**8.22**
10%	1	21	20	20	40	20.21	305,700	7.49
	2	21	20	20	40	19.48	286,594	7.02
	3	21	20	20	40	20.12	286,594	7.02
	Mean						**292,963**	**7.18**
20%	1	21	20	20	40	19.51	318,438	7.80
	2	21	20	20	40	21.79	254,750	6.24
	3	21	20	20	40	19.25	280,225	6.87
	Mean						**284,471**	**6.97**
30%	1	21	20	20	40	18.21	280,225	6.87
	2	21	20	20	40	17.27	222,957	5.46
	3	21	20	20	40	17.65	216,538	5.31
	Mean						**239,907**	**5.88**

Table A.A.8: 21st days' compressive strengths of control and trial mixes for class B size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	21	20	20	40	20.66	235,644	5.78
	2	21	20	20	40	20.20	305,700	7.49
	3	21	20	20	40	19.25	222,397	5.45
	Mean						**254,580**	**6.24**
10%	1	21	20	20	40	18.75	222,397	5.45
	2	21	20	20	40	19.76	254,750	6.24
	3	21	20	20	40	17.04	184,694	4.53
	Mean						**220,614**	**5.41**
20%	1	21	20	20	40	19.75	191,063	4.68
	2	21	20	20	40	19.52	280,225	6.87
	3	21	20	20	40	20.48	191,063	4.68
	Mean						**220,783**	**3.93**
30%	1	21	20	20	40	20.21	203,800	5.00
	2	21	20	20	40	20.57	206,348	5.06
	3	21	20	20	40	19.25	216,538	5.31
	Mean						**208,895**	**5.12**

Table A.A.9: 21st days' compressive strengths of control and trial mixes for class C size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	21	20	20	40	19.47	288,377	7.07
	2	21	20	20	40	20.57	257,807	6.32
	3	21	20	20	40	19.11	203,291	4.98
	Mean						**249,825**	**6.12**
10%	1	21	20	20	40	20.26	235,644	5.78
	2	21	20	20	40	20.99	318,438	6.98
	3	21	20	20	40	19.87	280,225	6.87
	Mean						**278,102**	**6.54**
20%	1	21	20	20	40	18.79	261,119	6.40
	2	21	20	20	40	18.44	191,063	4.68
	3	21	20	20	40	20.12	222,906	5.46
	Mean						**225,029**	**5.52**
30%	1	21	20	20	40	20.30	172,007	4.22
	2	21	20	20	40	19.58	242,013	5.93
	3	21	20	20	40	19.68	216,538	5.31
	Mean						**210,186**	**5.15**

Table A.A.10: 28th days' compressive strengths of control and trial mixes for class A size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	28	20	20	40	18.45	461,607	11.31
	2	28	20	20	40	18.58	431,801	10.58
	3	28	20	20	40	20.21	439,189	10.76
	Mean						**444,199**	**10.89**
10%	1	28	20	20	40	19.44	350,281	8.59
	2	28	20	20	40	19.63	324,806	7.96
	3	28	20	20	40	19.69	426,706	10.46
	Mean						**367,265**	**9.00**
20%	1	28	20	20	40	19.40	331,175	8.12
	2	28	20	20	40	19.37	312,069	7.65
	3	28	20	20	40	19.51	267,488	6.56
	Mean						**303,577**	**7.44**
30%	1	28	20	20	40	20.37	235,644	5.78
	2	28	20	20	40	18.94	280,225	6.87
	3	28	20	20	40	18.78	229,275	5.62
	Mean						**248,381**	**6.09**

Table A.A.11: 28th days' compressive strengths of control and trial mixes for class B size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [Kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	28	20	20	40	20.43	368,114	9.02
	2	28	20	20	40	20.00	389,360	9.54
	3	28	20	20	40	18.40	365,566	8.96
	Mean						**374,347**	**9.18**
10%	1	28	20	20	40	18.93	273,856	6.71
	2	28	20	20	40	18.93	295,510	7.24
	3	28	20	20	40	18.10	216,283	5.30
	Mean						**261,883**	**6.42**
20%	1	28	20	20	40	19.98	198,705	4.87
	2	28	20	20	40	20.55	254,750	6.24
	3	28	20	20	40	20.72	242,013	5.93
	Mean						**231,823**	**5.68**
30%	1	28	20	20	40	19.24	212,716	5.21
	2	28	20	20	40	19.43	178,325	4.37
	3	28	20	20	40	19.44	211,443	5.18
	Mean						**200,828**	**4.92**

Table A.A.12: 28th days' compressive strengths of control and trial mixes for class C size 20x20x40 hollow concrete blocks.

Percent replacement	Sample number	Test age [days]	Dimension [cm]			Weight [kg]	Failure Load [N]	Compressive strength [MPa]
			H	W	L			
0% or Control	1	28	20	20	40	20.63	235,644	5.78
	2	28	20	20	40	18.59	363,019	8.90
	3	28	20	20	40	19.81	350,281	8.59
	Mean						**316,315**	**7.75**
10%	1	28	20	20	40	18.56	280,225	6.87
	2	28	20	20	40	19.29	248,381	6.09
	3	28	20	20	40	19.60	222,906	5.46
	Mean						**250,504**	**6.14**
20%	1	28	20	20	40	19.75	203,800	5.00
	2	28	20	20	40	19.76	280,225	6.87
	3	28	20	20	40	19.91	222,906	5.46
	Mean						**235,644**	**5.78**
30%	1	28	20	20	40	19.59	191,063	4.68
	2	28	20	20	40	19.77	254,750	6.24
	3	28	20	20	40	19.27	210,169	5.15
	Mean						**218,660**	**5.36**

ANNEXE B

TYPE OF TEST CONDUCTED, NUMBER OF BLOCKS PRODUCED AND REPLACEMENT RATE OF CEMENT BY MARBLE DUST IN EACH CLASS OF HCB.

Table 1.13 Type of test conducted and replacement rate of cement by marble dust in class A, B and C HCB produced with size 20x20x40

Class of HCB	Control(0% replacement)		10% replacing Cement by waste marble dust		20% replacing Cement by waste marble dust		30% replacing Cement by waste marble dust		Total
	For Compressive Strength test	For water Absorption and Density test	For Compressive. Strength test	For Water absorption and Density test	For Compressive. Strength test	For Water absorption and Density test	For Compressive. Strength test	For Water absorption and Density test	
A	12	6+6=12	12	6+6=12	12	6+6=12	12	6+6=12	96
B	12	6+6=12	12	6+6=12	12	6+6=12	12	6+6=12	96
C	12	6+6=12	12	6+6=12	12	6+6=12	12	6+6=12	96
Total	36	36	36	36	36	36	36	36	***288***

ANNEXE C

GEOCHEMICAL TEST RESULT OF MARBLE WASTE

Geological Survey of Ethiopia:Geochemical Laboratory Directorate
Geochemical Laboratory Complete Silicate Analysis Report Format **Form G0004**
FILE ID ;0285/17 pvt **Originator;Berhanu Negesse**
Sample type; Marble(Dvit) **Date Submmitted; 02/23/2017**
Preparation :-200 MESH
Number of Sample: 1 **Element to be determined Major Oxides & Minor Oxides**
Analytical Method: LiBO2 FUSION , HFattack,GRAVIMETERIC,COLORIMETRIC and AAS
Analytical Results in PERCENT

FIELD NO	Lab No	PH
B.N-01	0285/17	9.32

Analysts
Tizita Zemene

Checked by	Approved by	Quality Control	DATE REPORTED
Tizita Zemene	Demisew Lemma	Awash Yirga	3/24/2017

Geological Survey of Ethiopia Central Geological Laboratory

[a]: - Geological laboratory complete silicate analysis report format for pH value of the sample

Geological Survey of Ethiopia:Geochemical Laboratory Directorate

Geochemical Laboratory Complete Silicate Analysis Report Format — Form G0004

FILE ID ;0285/17 pvt — Originator;Berhanu Negesse

Sample type; Marble(Dvit) — Date Submmitted; 02/23/2017

Preparation :-200 MESH

Number of Sample: 1 — Element to be determined Major Oxides & Minor Oxides

Analytical Method: LiBO2 FUSION , HFattack,GRAVIMETERIC,COLORIMETRIC and AAS

Analytical Results in PERCENT

FIELD NO	Lab No	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
B.N-01	0285/17	<0.01	2.41	<0.01	55.24	1.10	0.01	0.01	0.01	<0.01	<0.01	0.15	39.77

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Checked by: Gosa Hiale

Approved by: Demisew Lemma

Quality Control: Awash Yirga

DATE REPORTED: 3/24/2017

Geological Survey of ... Central Geological ...

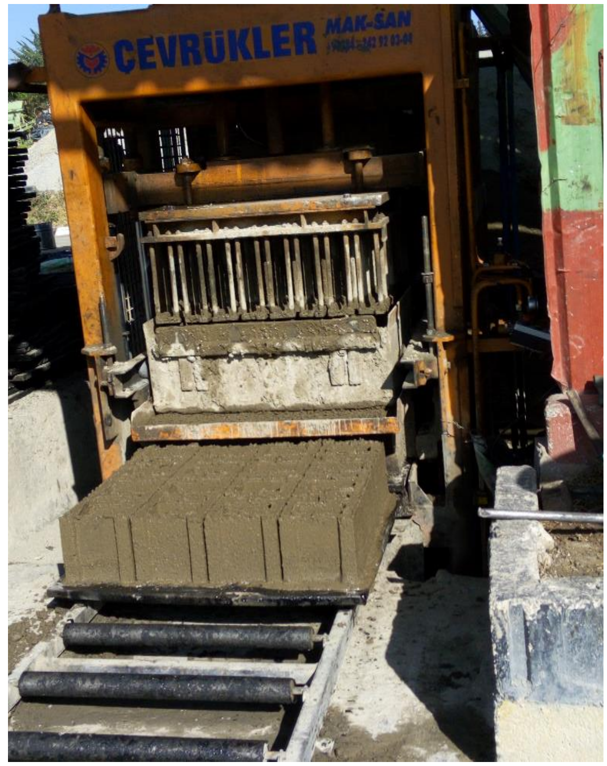
[b]: - Geological laboratory complete silicate analysis report format for chemical composition of the sample

Fig 1.1 Geological laboratory result of the waste marble dust, [a] and [b]

ANNEXE D

PHOTOGRAPHIC PRESENTATION

[a]: - Conveying the mixed ingredients



[b]: - Production of HCB with waste marble dust

[c]: - Produced HCB transportation

[d]: - Transportation to curing area

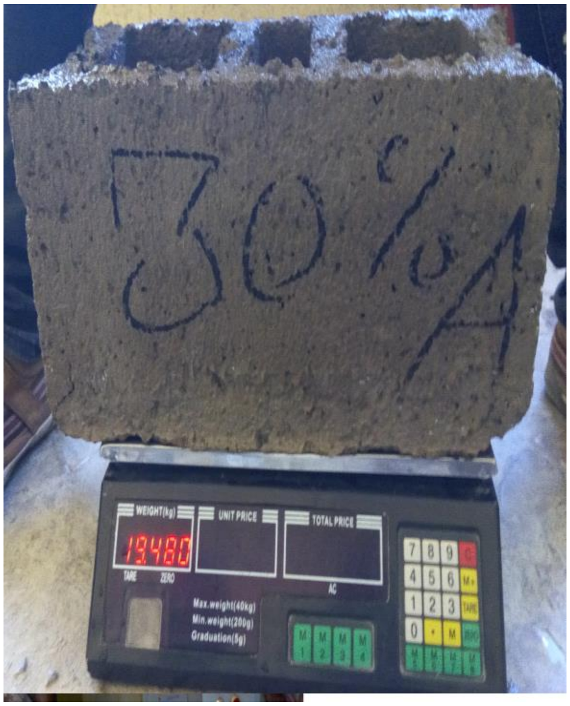
[e]: - Produced HCB transportation

[f]: - curing by coveering with plastics

Fig 1.2 Mixing, Conveying, production, transportation and curing of produced blocks [a] to [f].

[g]: - Arranging according to their rate of replacement

[h]: - Preparing for compressive strength test



[i]: - Measuring weight of trial blocks [j]: - Compressive strength test

Fig 1.3 Compressive strength test in laboratory according to their trial proportion [g] to [j].

[a]: - Measuring weight of trial blocks [b]: - Immersing blocks in water

Fig 1.4 Water absorption test in the laboratory according to their trial proportion [a] and [b].

[a]: - Measuring the weight of trial blocks

[b]: - Keeping oven for 24 hrs

[c]: - Measuring the weight of trial blocks after 24 hr in oven

Fig 1.5 Density test in the laboratory according to their trial proportion [a] to [c].

[a]: - Measuring weight of waste marble powder for fineness test

[b]: -Finense test of cement using Blaine fineness

Fig 1.6 Fineness test for waste marble dust and cement used in the research [a] and [b].