PERFORMANCE OF HOLLOW CONCRETE BLOCKS WITH CRUSHED WASTE GLASS AS PARTIAL REPLACEMENT OF FINE AGGREGATE

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ADVISOR’S APPROVAL SHEET

This is to certify that the thesis entitled “Performance of hollow concrete blocks with crushed waste glass as partial replacement of fine aggregate: a case of Hawassa” submitted in partial fulfillment of the requirements for the degree of Master’s with specialization in construction Technology and Management, the Graduate program of the faculty of Civil Engineering and Built environment, and has been carried out by Yosef Kuma ID.No. PG CoTM/048/11 under our supervision. Therefore, we recommend that the student has fulfilled the requirement and hence hereby can submit the thesis to the school.

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Name of Co-advisor	Signature	Date

DECLARATION

I hereby declare that this thesis prepared for the partial fulfilment of the requirements for MSc. Degree in construction technology and management entitled “Performance of class C hollow concrete blocks with crushed waste glass as partial replacement of fine aggregate: a case of Hawassa" is prepared with my effort except for secondary sources which have been acknowledged, as listed in the bibliography. I have made it independently with the close advice and guidance of my advisors.

Name: Yosef Kuma Signature: ______________ Date: _______________

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LIST OF ABBREVIATIONS

ASTM	American Standard for Testing and Material
BS	British standard
CEM	Cement
CES	Compulsory Ethiopian Standard
cm	Centimeter
COVID	Coronavirus Diseases
CWG	Crushed Waste Glass
ES	Ethiopian Standard
F.M	Fineness modulus
GTZ	German Technical Co-operation
HCB	Hollow Concrete Block
IS	Indian standard
Kg	Kilogram
Kg/m^3	Kilogram per cubic meter
KN	Kilonewton
m^3	Meter cube
mm	Millimeter
MPa	Mega Pascal
OPC	Ordinary Portland cement
PPP	Pozzolanic Portland cement
SNNPS	Southern nation nationalities and peoples
SSD	Saturated Surface Dry

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ABSTRACT

Construction is booming in developing countries like Ethiopia. As construction is increasing, demand and price of the construction materials are increasing. Among building construction components hollow concrete block is being widely used. From concrete block making materials fine aggregate is higher constituent. The uses of river sand as fine aggregate leads to exploitation of natural resources and also environmental concerns related to the disposal of various waste materials have escalated to a worrying level, among those: crushed wastes glass is one of them. Therefore, to make the construction industry sustainable, the use of waste materials in place of natural resources is one of the recommended. The main objectives of this study was to investigate the performance of class C hollow concrete blocks with crushed waste glass as partial replacement of fine aggregate and to determine the replacement percentages at which crushed waste glass can be effectively put into service and also compare the cost of crushed waste glass partially replaced in hollow concrete block with the conventional ones. The method used was experimental study. The crushed waste glass partial replaced fine aggregate with 10%, 20% and 30% by volume and the control mix was prepared. The compressive strength test was carried out at the 7th, 14th and 28th days, whereas the density and water absorption tests were carried out on the 28th day. As per the finding, the control mix compared with the replacement specimen, the density is decreased as the proportion of crushed waste glass increases and decreases by 5.6% at a 30% replacement, the water absorption decreases as crushed waste glass content increases and it decreased by 2.5% at a 30% replacement, the compressive strength with up to 20% replacement increases by 59.72%, but after that, it starts decreasing for 30% replacement by 10.64%, results showed that replacement of 20% fine aggregate by crushed waste glass was found to have optimal compressive strength, and also the production of block using 20% crushed waste glass saves cost compared to the conventional once by 2.06% in 1m^2 area.

Keywords*: Crushed waste glass, Fine aggregate, Hollow concrete blocks.*

CHAPTER 1

INTRODUCTION

1.1 Background

The natural resources in the world are continuously decreasing due to the manufacturing of the products and their impact on the environment since disposing of the unwanted products is becoming issues that need to be addressed and resolved. This can be reduced by adopting the policy of 3Rs; Reduce, Reuse, and Recycle (Umar et al., 2017).

In recent years, the rapid growth of the construction industry has led to environmental problems caused by excessive mining and usage of natural resources such as aggregate and cement. Approximately 275 million tons of new aggregate is extracted annually in the United Kingdom and this is estimated to increase by 1% each year. Concerns over the damage to the surrounding environment, destruction of the ecological balance, and emission of greenhouse gases have become increasingly severe (Meng et al., 2018). Therefore, to make the construction industry sustainable and to solve the environmental problem reuse industrial waste products as an alternative material for concrete making should be devised. Among building construction materials hollow concrete block is one of them.

Hollow concrete blocks have been used in different construction applications, such as partition wall, paving, and floor blocks are among others. The most unique feature of concrete blocks is their ability to be molded into different shapes, thicknesses, densities, and strengths for different civil engineering applications (Osuji & Egbon, 2015). For partition wall blocks, lightweight, better sound and thermal insulation are the important functional properties for buildings. One of the ingredients used for concrete block making material is fine aggregate. Fine Aggregate is the major component (up to 80% by volume) in concrete blocks and vital in influencing the properties of concrete blocks. Since the usage of conventional aggregate which is river sand has not environmentally friendly and causes depletion of natural resources (Medina et al., 2012).

Now, a day a variety of waste materials have been recycled and used as aggregate in concrete blocks. Although generally exhibiting lower strength, lower density, and higher water absorption, blocks incorporating waste materials can satisfy the requirements of blocks with a proper aggregate replacement ratio. This is because the quality requirements for raw materials used in the production of concrete blocks are relatively low compared to other conventional concrete products. Moreover, the majority of waste materials have their unique characteristics and can be utilized in concrete blocks for special applications. It has been found that certain waste materials produced by different industrial processes can be very useful in construction, they can provide the required properties, strength, and safety (Sekhar et al., 2015).

Environmental concerns related to the disposal of various waste materials have escalated to a worrying level. Depending on the local industries, different types of waste are generated in huge quantities every year. Hence, the demand for more sustainable development has further increased the importance of green construction. In recent years, extensive study efforts have been made to recycle wastes for possible use in the production of concrete products. From different types of material wastes glass is one of them. It is a major component of the solid waste stream in many countries. It can be found in many forms, including container glass, flat glass such as windows, bulb glass, and cathode ray tube glass. Although a small proportion of the post-consumer glass has been recycled and reused, a significant proportion, which is about 84% of the waste glass generated in the united kingdom, is sent to landfill (Meng et al., 2018).

According to the Ethiopian Ministry of Environment and Forest (2016), in Addis Ababa from daily total solid wastes 2.60% is glass, in Hawassa city from daily total solid waste glass is 1.60%. On average in Ethiopian cities from daily total solid waste 1.20% of waste glass is generated per day. Therefore, to make the construction industry sustainable, the use of waste materials in place of natural resources is one of the best approaches. Hence, this study is aimed to conducted the performance of class C hollow concrete blocks with crushed waste glass as partial replacement of fine aggregate.

1.2 Statement of The Problem

Construction is booming in developing countries like Ethiopia. Due to urbanization, there are many building constructions project in the country. As construction is increasing, demand and price of the construction materials such as reinforcement bar, cement, sand, and the like are increasing. Among building construction components hollow concrete block is being widely used in the construction of residential buildings, factories, and multi-storied buildings (Mikiyas, 2019).

According to Ethiopian Standard (Dinku, 2002), hollow concrete blocks are classified into three classes: Class A, Class B, and Class C. Classes A and B are load-bearing and Class C is non-load bearing units. For the production of the Class C, it requires more fine aggregate (up to 80% by volume) than load-bearing blocks. The increasing demand for fine aggregates and uses of river sand as fine aggregate leads to exploitation of natural resources, depletion of riversides, lowering of the water table, sinking of bridge piers, and erosion of river bed (Desalegn, 2019).

Waste glass production has gradually increased over the recent years due to an ever-growing use of glass products. This crushed waste glass is being dumped into landfill sites. The landfilling of waste glass is undesirable because waste glass is non-biodegradable which makes it environmentally unfriendly (Topcu and Canbaz, 2004). In recent years, extensive study efforts have been made to reutilize waste glasses for possible use in the production of concrete products in developed countries. According to the information from different construction stakeholders in Ethiopia, there is no construction company, business center, or institution that utilized crushed waste glass as an alternative construction material for conventional concrete or hollow concrete blocks.

Generally, as the river is being exploited as the main source of fine aggregate, the cost of this aggregate is increasing in our country and waste glasses are dumped as garbage materials. Hence this garbage can be used as an additional source to be utilized as an alternative reusable material to partially replace the fine aggregate. This study was conducted to investigate the performance of class C hollow concrete blocks with crushed waste glasses as a partial replacement of fine aggregate.

1.3 Research Questions

I. What are the performances of the specific percentages of waste glass in hollow concrete blocks compared to conventional hollow concrete blocks?

II. Are the produced hollow concrete blocks by the crushed waste glass economically feasible in comparison with conventional hollow concrete blocks?

1.4 Research Objectives

1.4.1 General objective

The general objective of this study is to investigate the performance of class C hollow concrete blocks with crushed waste glass as partial replacement of fine aggregate.

1.4.2 Specific objectives

- ✓ To investigate the performance of class C hollow concrete blocks with crushed waste glass as partial replacement of fine aggregate.
- ✓ To determine the optimum percentage of replacement at which crushed waste glass can be effectively put into service in class C hollow concrete block production.
- ✓ To compare the cost of class C hollow concrete block with optimal replacement of fine aggregate by crushed waste glass and that of conventional.

1.5 Significance of The Research

The study is believed to be beneficial since its aim was to partially replace fine aggregate in class C hollow concrete blocks using crushed waste glass. The hollow concrete block with optimal replacement of crushed waste glass as fine aggregate plays a lot of significant role such as enhancing the performance of HCB, like density, water absorption, and strength. It also helps to reduce the demand of fine aggregate for the production of the concrete blocks, contributes its part in preventing sand depletion and reduce the production cost of hollow concrete blocks. Besides, the replacement plays a great role in minimizing solid waste disposal, the related costs incurred for transportation of waste and the space which would have been occupied by the waste glass. Therefore, generally speaking the production of concrete block using crushed waste glass is environmentally friendly compared with river sand.

1.6 Scope and Limitation of The Research

The research addresses, the physical, and mechanical properties of materials used for production of class C hollow concrete blocks like density, water absorption, and compressive strength of class C hollow concrete block using blended crushed waste glass and fine aggregate. The chemical composition of the crushed waste glass has also been studied. The scope was limited to crushed waste glass as a partial replacement of fine aggregate in class C hollow concrete block.

Due to COVID-19 pandemic, time and resource limitation, the study of performance of class C hollow concrete block with crushed waste glass as partial replacement of fine aggregate between 21-29% and other further study were not conducted.

CHAPTER 2

LITERATURE REVIEW

2.1 Concrete Block

Concrete blocks are masonry units, usually solid or with single or multiple hollows, made of various ingredients: cement, aggregate such as sand, gravel, crushed stone, air-cooled slag, coal, cinders, expanded shale or clay, expanded slag, volcanic cinder (pozzolana), pumice and scoria and water (Dinku, 2002).

Concrete blocks are simple to construct both for internal and external walls and also, they are suitable for additional aesthetic and finishing materials. The manufacture of hollow concrete blocks requires constant monitoring to produce blocks that have the required properties such as shape, appearance, texture and color and apparent density, water absorption, and compressive strength, all units shall be free of cracks or other defects that interfere with the proper placing of the unit or impair the strength or the performance of construction (Indian Standard 2185 (part I-1979).

2.2 Type and Production of Concrete Block

2.2.1 Types of concrete blocks

Concrete blocks can be classified in many ways, for example depending on their weight, shape, size, material of production, compressive strength, and purposes.

According to Ethiopian Standard hollow concrete blocks are classified into three: Class A, Class B and Class C. Class A and B are load-bearing units suitable for use as external walls pointed, rendered, plastered, internal walls, or partitions and Panels in steel-framed and reinforced concrete framed buildings. Class C, non-load bearing units suitable for use as - Non-load bearing walls and partitions, and Non-load bearing internal panels in steel-framed and reinforced concrete framed buildings. Depending on their weight and shape concrete block is divided into hollow concrete and solid blocks.

I. Hollow concrete block (HCB)

This type of concrete block is the most common type and widely used type that have two or three hollow cores. They are lightweight, economical, and needs semiskilled laborers for the production. Hollow concrete blocks are weak against lateral loads. The advantages of using HCB are that they are readily available product, sound and thermal resistance, high fire resistance, can be increased the lateral load resistance by reinforcement, and has a 20+ year lifespan (Global, 2014). The figure 2.1 below shows different hollow concrete blocks.

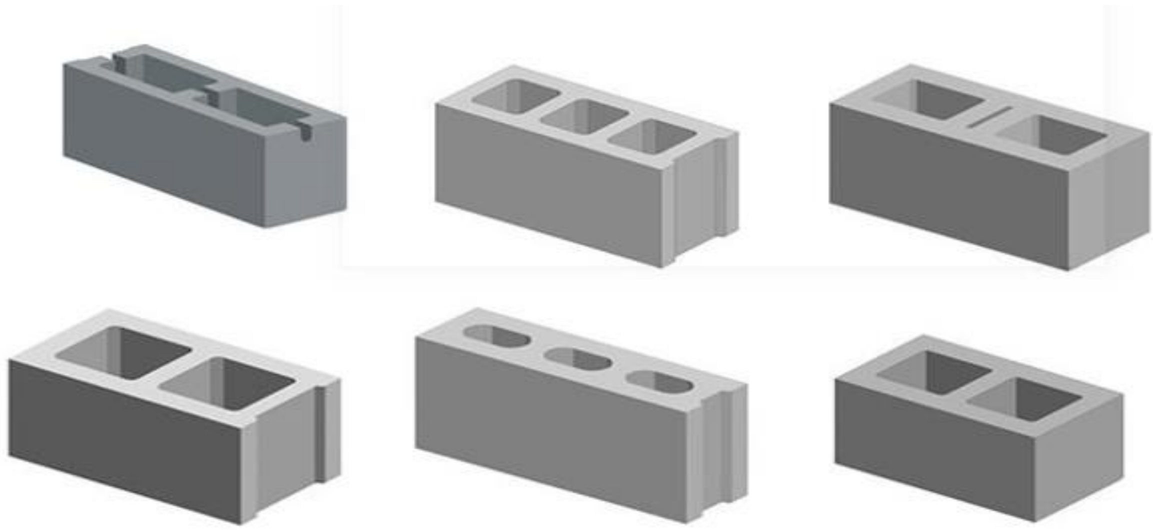

Figure 2.1 Different hollow cores block (Source: building materials. blogspot.com).

II. Solid concrete block

Solid concrete blocks are heavier than hollow concrete blocks. Mostly manufactured solid block size is 400mmx200mmx150 mm size. These blocks are mostly used for load-bearing wall construction (Michael, 2012). Figure 2.2 below shows a solid block.

Figure 2.2 Solid concrete block (Source: building materials. blogspot.com).

Concrete blocks depending on their size or thickness they are three different dimensions according to Ethiopian standard such as 10cm x 20 cm x 40 cm, 15 cm x 20 cm x 40 cm, and 20 cm x 20 cm x 40 cm.

2.2.2 Hollow concrete blocks production process

2.2.2.1 Raw materials

Portland cement (OPC or PPC), aggregates, and water are common raw materials used to make a concrete mixture for the production of hollow concrete blocks. But concrete mixture used for blocks 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 a nominal aperture of 9.5 mm 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 Ethiopian standard (ES 596:2001).

2.2.2.2 Mixing

In the case of a hand-molded block where compaction is done manually, the concrete mix should be sufficiently consistent to enable remolding immediately after casting. The consistency of the mix should be such that it may cohere when compressed in the hand without free water being visible. Too little water causes the mix to be friable, while too much water causes difficulty in the immediate withdrawal of the mold. 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 color and consistency. Ten percent extra cement may be added if hand-mixing is an alternative according to Indian standard 2185 (part I-1979).

In the case of machine-molded blocks, 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 the 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.

2.2.2.3 Compaction and placing

According to Indian standard 2185 (Part I) – 1979, manual compaction, the mixture shall be placed into the mold in layers of about 50 to 75 mm and each layer thoroughly tamped with suitable tampers 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 hollow concrete block and transported and remains for 24 hours on a wooden pallet then it is be cured covered by a plastic sheet to enhance the curing process and preventing the water from evaporation.

2.2.2.4 Curing

Indian standard 2185 (Part I) – 1979 recommends for manufactured blocks on the site shall be cured in a water tank or a curing yard by being kept thoroughly moist with water for at least 14 days. When the blocks are cured in an immersion tank, the water of the tank shall be changed at least every 4 days. On the other hand, steam curing can be adopted for a reduction in curing time. 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. The blocks shall not be used before one month after production to complete initial shrinkage before blocks are laid in the wall. On the other hand, GTZ low-cost housing manual Volume I recommend 10 days of curing time, in addition to this, the date of production must be written on blocks for identification whether it is ready or not for construction.

2.2.2.5 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 596:(2001).

2.3 Uses of Hollow Concrete Block for Construction

The hollow concrete block uses for different purposes in construction such as for filler block in ribbed slabs, for load-bearing and non-load bearing wall construction.

2.3.1 Hollow concrete filler blocks for ribbed slabs

Hollow concrete filler blocks for a ribbed slab shall be manufactured in approved vibrated machine and shall be so shaped as to give a minimum bearing of 25 mm of the filler blocks on the joist. 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 cement concrete filler blocks specify to conform requirements for size and shape and breaking strength. A typical section of the hollow cement concrete filler block to span between joists kept at 600 mm centers. If the hollow cement concrete filler block has to span between joists kept at 750mm centers or above, the block should be suitably reinforced. The blocks shall be so prepared, that at any point it shall have a thickness of not less than 25 mm with maximum variation in the dimensions shall be not more than + 1.5 mm for height and breadth and +3.00 mm for length. In addition to this, blocks shall be prepared to have a bearing of not less than 25 mm on the joists. On the other hand, Ethiopian standard recommended maximum dimensional variation shall be +5 mm and the nominal dimension is listed in table 2.1 below.

Table 2.1 Nominal dimensions of hollow concrete filler blocks [ES]

Height (mm)	Breadth (mm)	Length (mm)	Face shell (mm)	Web (mm)
140	400	200	20	20
180	400	200	25	20
240	400	200	30	25

2.3.2 Hollow concrete blocks for wall construction

Hollow concrete blocks used for wall construction classified as load-bearing and non-load bearing depends on their structural function (Dinku D., 2002). According to ASTM C90-70 hollow concrete block, load-bearing concrete blocks have three weight classifications those are normal weight, medium weight, and lightweight blocks as listed in Table 2.2 and shall conform 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 exposed to moisture penetration. But grade S blocks 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 shall conform all requirement listed in table 2.3 and non-moisture-controlled units designed as type II (N-II and S-II) and shall conform all requirements except moisture content requirements listed in table 2.3

On the other hand, non-load bearing hollow concrete blocks are manufactured in accordance with specifications ASTM C129-70. 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.

Table 2.2 Weight classification of hollow concrete block ASTM C90-70

Classification of hollow block	kg/m^3
Lightweight	Normal weight
Medium weight	Normal weight
Normal weight	2002 or more

Table 2.3 Moisture content requirement for type I units ASTM C90-70 & ASTM C129-70

Linear shrinkage percent	Moisture content requirement max percent of total absorption average of 3 units		
	Humidity condition at a job site or point of use		
	Humid (Average annual relative humidity above 75%)	Intermediate (Average annual relative humidity 50 to 75%)	Arid (Average annual relative humidity less than 50%)
0.03 or less	45	40	35
From 0.03 to 0.045	40	35	30
0.045 to 0.065, max	35	30	25

2.4 Performance Requirements of Concrete Block

All units shall be sound and free of cracks or other defects that 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 be free of chips, cracks, or other imperfections, except that if not more than 5 percent of a batch contains slight cracks or small chippings not larger than

25 mm [ASTM C90-70] or 10mm [ES596:2001] or [IS: 2185-1979], this shall not be deemed grounds for rejection. There are different standards for performance or physical requirements of the hollow concrete block such as dimension and tolerance of block, the density of block, water absorption, drying shrinkage, moisture content, compressive strength, and the like.

2.4.1 The standard dimension and tolerance of hollow concrete block

Hollow concrete block shall be referred to by its nominal dimensions. The term 'nominal' means the standard dimension which designed by manufacturer plus thickness of the mortar joint. For modular size units' nominal dimension equal to standard dimension plus 9.53 mm but for non-modular size units it exceeds the standard dimension by 3.18 to 6.35 mm [ASTM C90-70]. Other standards such as Indian standards [IS:2187-1979] recommended mortar joint 10 mm for modular size and 6 mm 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 the 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 C90-70 and ASTM C129-70 overall dimensions tolerance (length, width, and height) of the hollow concrete block shall not differ by more than 3.18 mm from a specified standard dimension. In addition to this, face shells and webs thickness shall not less than ½ in or 12.7 mm for non-load bearing hollow concrete block but load-bearing shall conform the Table 2.4. In the case of Indian standard IS: 2185:1979 overall dimensions shall not differ by +5 mm for length and +3 mm for height and breadth in addition to this face shells and webs thickness shall conform the table 2.4.

British standard BS: 6073-part I 1981 specify the maximum dimensional deviation for masonry units by measuring at four corners of end faces for length and for height at six positions using caliper it should be +3 mm or -5 mm and +2 mm for thickness by measuring at seven positions. On the other hand, the Ethiopian standard [ES 596:2001] specify maximum dimensional variation (length, height, breadth), it should be + 5mm for nominal dimensions of concrete masonry blocks these are listed below in Table 2.4. In addition to this, face shells and webs thickness of hollow units shall be at least one-sixth of the overall breadth of a unit or 25mm whichever is the greater.

Table 2.4 Minimum face-shell and web thickness [ASTM C90-70], [IS: 2185-1979] and [ES 596:2001]

Minimum face-shell and web thickness [ASTM C90-70]			Minimum face-shell and web thickness [IS: 2185-1979]			Nominal dimensions of hollow concrete blocks [ES 596:2001]		
Nominal width (mm)	Face shell thickness (mm)	Web min (mm)	Nominal width (mm)	Face shell thickness (mm)	Web min (mm)	Length mm	Breadth mm	Height mm
102	19	19	Less than 100 mm	25	25	400	100 150 200	200
152	25	25	100 to 150	25	25	500	100 120 150 200	100 120 150 200
203	25	25	150 to 200	30	25	600	100 120 150 200	100 120 150 250

2.4.2 The block density

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 the aggregate because the particle density of individual grading fraction can differ considerably and thus will affect the density of concrete. 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 overall volume computed in cubic centimeters. According to Ethiopian standard 596:2001 and Indian standard 2185(part 1)-1979 three blocks shall be taken for average density and it should conform to the requirements specified in table 2.5 below. The blocks shall then be weighed in kilograms (to the nearest 10 g) and the density of each block calculated as follows.

$$\text{Densiy} = \frac{\text{mass of a block in kg}}{volume\ of\ the\ specimen\ in\ cm3} * \frac{10^6 kg}{m3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Eqn\ 2.1$$

Table 2.5 Density classification of concrete masonry unit's ES 596:2001 and IS: 2185-1979

Class of hollow concrete block	Ethiopian standard ES 596:2001 (kg/m^3)	Indian standard IS: 2185-1979 (kg/m^3
A	900-1200	1500
B	900-1200	1000-1500
C	900-1200	1000-1500

2.4.3 The 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 by 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 10 mm or coarser wire mesh, visible surface water is 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 table 2.6. On the other hand, the Ethiopian standard [ES 596:2001] specifies 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 but 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 2.6 Absorption requirements of load-bearing hollow concrete block [ASTM C90-70]

Grade	Water absorption max (kg/m^3)			
	Oven dry weight classification (kg/m^3)			
	Lightweight		Medium weight	Normal weight
	>1362 (kg/m^3)	1362 – 1682 (kg/m^3)	1682 -2002 (kg/m^3)	< 2002 (kg/m^3)
N-I & II	-	290	240	210
S-I & II	320	-	-	-

2.4.4 The drying shrinkage

The drying shrinkage is defined as the change in the linear dimension of a 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 maybe takes 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. Units when unrestrained being the average of three units shall not exceed 0.1 percent [IS: 2185:1979].

2.4.5 The moisture contents

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.

2.4.6 The compressive strength

The strength of hollow concrete is closely related to the specimen size and shape, method of pore formation, the direction of loading, age, water content, water-cement ratio, degree of compaction, and cement content characteristic of its ingredients used, method of curing, size and number of holes created. Both the hollow structure of the air holes and the mechanical condition of the pore shells have a great influence on the compressive strength of the hollow concrete block. It is also been found that a reduction in density due to the formation of holes will result in a significant drop in strength. Generally, the compressive strength increases linearly with the 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. Compressive strength of a concrete masonry unit shall be taken as the maximum load in Newton divided by the gross cross-sectional area of the unit in square millimeters finally the results of the nearest 0.1 N/mm2, separately for each unit and as the average for the six units will be recorded (ASTM C129- 70).

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 minimum compressive strength at 28days of hollow concrete block for load-bearing such as class A and B and also for non-load bearing which is class C listed in table 2.7.

Table 2.7 Minimum comprehensive strength at 28 days for concrete blocks [ES]

Type of hollow concrete block	Classes	Minimum compressive strength (N/mm2)	
		Average unit of 6 units	Average of individual units
Load-bearing	A	4.2	3.8
	B	4	3.2
Non-Load bearing	C	2	1.8

2.5 Performance Requirements of Fine Aggregate in Concrete

Aggregate provides technical advantage on concrete which has higher volume stability better than the cement paste alone. So, before using aggregate it is important to examine whether those aggregates fit for the purpose to which they are intended to be used and tests on-site and laboratory should have to be made. Some of the requirement discussed below:

2.5.1 Silt content

Sand is a product of natural or artificial disintegration of rocks and minerals. Sand is obtained from glacial, river, lake, marine, residual, and wind-blown (very fine sand) deposits. These deposits, however, do not provide pure sand. They often contain other materials such as dust, loam, and clay that are finer than sand. Therefore, it is necessary that one make a test on the silt content and checks against permissible limits. A simple test that can be made on-site to give a guide to the amount of silt in natural sand is the 'field settling' test. This test should not be used for crushed rock sands. According to the Ethiopian Standard it is recommended to wash the sand or reject if the silt content exceeds a value of 6% (Dinku, 2002).

2.5.2 Grading of fine aggregate

Fine aggregate grading has a greater effect on the workability of concrete than coarse aggregates. The grading determines the paste requirement for a workable concrete since the amount of void requires needs to be filled by the same amount of cement paste in a concrete mixture. To obtain a grading curve for aggregate, sieve analysis will be conduct.

According to BS 882 or ASTM the grading requirement of fine aggregate, are summarized as shown in Table 2.8. (ASTM C-136)

Table 2.8 BS and ASTM grading requirements of fine aggregate

Sieve Size	Percentage of passing (%)				
	BS882:1973				ASTM Standards
	Grading Zone 1	Grading Zone 2	Grading Zone 3	Grading Zone 4	
9.5mm	100	100	100	100	100
4.75mm	90-100	90-100	95-100	95-100	95-100
2.36mm	60-95	75-100	85-100	95-100	80-100
1.18mm	30-70	55-90	75-100	90-100	50-85
600µm	15-34	35-59	60-79	80-100	25-60
300µm	5-20	8-30	12-40	15-50	10-30
150µm	0-10	0-10	0-10	0-15	2-10

2.5.3 Fineness modulus

Using the sieve analysis results, a numerical index called the fineness modulus (FM) is often computed. The FM is the sum of the total percentages coarser than each of a specified series of sieves, divided by 100. The specified sieves are 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600µm, 300 µm, and 150 µm (No. 4, 8, 16, 30, 50, and 100). Note that the lower limit of the specified series of sieves is the 150 μm (No. 100) sieve and that the actual size of the openings in each larger sieve is twice that of the sieve below. The coarser the aggregate size, the higher the FM. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 as called for in ASTM C 33. It is used as an index to the fineness or coarseness and uniformity of aggregate supplied, but it is not an indication of grading since there could be an infinite number of grading which will produce a given fineness modulus. The following limits may be taken as guidance (Addissie, 2005).

Fine sand: F.M. 2.2 - 2.6, Medium Sand: F.M. 2.6 - 2.9 and Coarse Sand: F.M. 2.9 - 3.2. Sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete However, it is clear that one parameter, the average, cannot be representative of a distribution: thus, the same fineness modulus can represent an infinite number of totally different size distributions or grading curves.

2.6 Glass as A Partial Replacement in Concrete

Glass is one of the oldest man-made materials in the world. Glass is an irregular (non-crystalline) solid material. Glasses are usually brittle and optically transparent. Glasses are produced in many forms and the most familiar types of glass used for centuries in window vessels is soda-lime glass made of about 75% silica (SiO_2) plus Na_2O, CaO and several smaller additives. Glass can also be produced in many forms these include packaging or container glass, flat glass, bulb glass, and cathode ray tube glass and all these glasses have a limited life span in which they are produced, and they need to be reused or recycled for other purposes, in order not to cause environmental problems (Sekhar et al., 2015).

Glass is produced from three main ingredients which are sand, soda ash, and limestone. All glass jars and glass bottles are recyclable, this includes wine, beer, soft drinks, as well as colored glass. Heat-treated glass including drinkware, ceramics, plate glass (door and window panes) cannot be recycled using the recycled service because the melting temperature of the heat-treated glass is higher than that of the glass and bottle jar (Carless, 1992). When there is a mix up between the bottle and jar recycling, it can prevent the molten glass to extrude properly or it can make the new bottles too brittle to use. Before glass should be recycled, the plastic lids and caps should be removed from the glass, thereby placing them in the waste bin. It is not a must to rinse glass before crushing; the remaining particles should be scraped, or preferably it should be rinse, the dishwater should be used rather than freshwater, and the paper label on the glass may be removed if desired or it can also be recycled with the glass. After doing all this (collection), glass bottles and jars can be crushed using the manual means or mechanical separation. The majority of this glass is melted in the furnace and usually by the addition of other raw materials. This glass can be used for building aggregate in water filtration and for construction materials (Carless, 1992). The application of many industrial by-products in the construction industry is now well developed, and this helps in improving sustainability in two ways; the reuse of the materials which otherwise will burden the environment and will occupy scarce land resources. Secondly, it minimizes the degradation of land and the surroundings, as a result of relatively less excavation. The sample of glass recycled waste is shown in figure 2.3.

Figure 2.3 A sample of recycled glass waste cullet stockpile in West Virginia (1993) (Source: Rajabipour et al., 2012).

2.6.1 Manufacturing Process, Classification, and Uses of Glass

2.6.1.1 Manufacturing Process of Glass

Glass is manufactured in the following four steps (Du & Tan, 2014).

a. Melting

The raw materials — lime, soda, and sand — separately cleaned, ground, sieved, and batched in definite proportion and mixed with water are fused in a continuous type (tank) furnace or batch-type (pot) furnace. The charge in the first stage melts, forming a bubbly, sticky mass, and as the temperature is raised (1100° C–1200°C) it turns to a more water liquid and the bubbles rise to the surface.

When all the carbon dioxide has escaped out of the molten mass, decolourisers such as MnO2 or nitre are added to do away with ferrous compounds and carbon. The coloring salts are added at this stage. Heating is continued till the molten mass is free from bubbles and glass balls. As the glass cools (800° C), it is ready to be drawn or floated to its desired thickness and size at the other end of the furnace.

b. Forming and Shaping

The molten glass can be fabricated to desired shapes by any one of the following methods: Blowing - A 2 m long and 12 mm diameter blowpipe is dipped in the molten glass and taken out. It is held vertically and is vigorously blown by the operator. The sticking molten glass takes the shape of a hollow ball. On cooling, it is reheated and the blowing operation repeated a number of times till the desired articles are ready.

Flat Drawing - The process of drawing the glass up into a sheet begins when a grille (bait) is lowered into the glass in the kiln. In a short time, the liquid molten glass adheres to the bait, and as the bait is slowly lifted it draws a sheet of glass. The bait and the drawn sheet of glass are then drawn through rollers, the bait is cracked off and a continuous sheet of glass is drawn up. This sheet is then slowly cooled in a chamber and annealed for cutting into the proper size.

Compression molding - In this process molds are used to obtain the articles of desired shapes. Spinning - A machine is used to spin the molten glass. The fibers so produced are very fine and are used for heat and sound insulation.

c. Annealing

Glass articles are allowed to cool under room temperature by passing through different chambers with descending temperature. If cooled rapidly, the glass being a bad conductor of heat, the superficial layer cools down first and strain develops in the interior portions, which causes unequal expansion and the articles are likely to crack.

d. Finishing

After annealing the glass articles are cleaned, ground, polished, cut and sandblasted.

2.6.2 Classification of glasses

I. Depending upon the constituents

Depending upon the constituent's glasses are classified as soda-lime glass, lead glass, and borosilicate glass.

Soda-lime glass is also known as soda-ash glass, soda glass, or soft glass. Soda-lime glass is obtained by fusing a mixture of silica, lime, and soda. The quality of this glass can be improved by adding alumina and magnesium oxide and the glass is then called crown glass. This is the most common type of glass used indoors, windows, and for making glass-wares such as bottles (Du & Tan, 2014).

Lead glass is also known as flint glass is obtained by fusing a mixture of silica, lead, and potash. It is free from iron impurities and is colorless. Lead glass has a high shining appearance and can take a polish. It is not affected by temperature. Electric bulbs, optical glasses, cut glass, ornamental glassworks, and radio valves are some of the articles made from it (Du & Tan, 2014).

II. Depending on commercial purpose glasses are classified as follows (Du & Tan, 2014).

Sheet glass - is used for glazing doors, windows, and partitions and is obtained by blowing the molten glass into the shape of a cylinder. The ends of the cylinder so produced are cut away and the cylinder is flattened over a plane tray.

Plate glass - is used for all engineering purposes and is superior to sheet glass. A plate glass differs from a sheet glass in that it has a parallel, distortion-free surface obtained by grinding or floating process. It is produced by pouring the molten glass on casting tables and leveling it to a uniform thickness. Both the glass surfaces are then ground, smoothened and polished. Tempered glass - is made from plate glass by reheating and sudden cooling and is 3 to 5 times stronger than plate glass. Although not unbreakable, it resists bending stress better than plate glass, and, when broken, the pieces are relatively small in size. It is used extensively in sports arenas, sliding doors, and curtain walls.

Block glass - is a hollow sealed made by fastening together two halves of pressed glass. It is used for making partitions.

2.6.3 Uses of glass for concrete production

The following are the major advantages of glass for concrete production:(Gautam et al, 2012).

- ✓ It has basically zero water absorption, it is one of the most durable materials known to man. With the current emphasis on the durability of high-performance concrete, it is only natural to rely on extremely durable ingredients.
- ✓ The excellent hardness of glass gives the concrete an abrasion resistance that can be reached only with few natural stone aggregates or the addition of metallic fines typical of special floor toppings.
- ✓ For a number of reasons, glass aggregate improves the flow properties of fresh concrete so that very high strengths can be obtained even without the use of superplasticizers.
- ✓ The esthetic potential of color-sorted glass, not to mention specialty glass, has barely been explored at all and offers numerous novel applications.
- ✓ Very finely ground glass has pozzolanic properties and therefore can serve both as partial cement replacement and filler

2.7 Properties of Crushed Waste Glasses in Concrete

2.7.1 Physical properties of crushed glass in concrete

The physical properties of glass aggregates are those that refer to the physical structure of the particles that makes up the aggregate. Crushed glass particles are generally angular in shape and can contain some flat and prolonged particles. The degree of angularity and the amount of flat and elongated particles depend on the degree of processing. Smaller particles, resulting from extra crushing, will exhibit less angularity and reduced quantities of flat and elongated particles. Proper crushing can nearly remove sharp edges and the corresponding safety hazards associated with manual handling of the product. The actual coefficient of permeability depends on the gradation of the glass, which in turn depends on the degree of processing (crushing and screening) to which the glass is subjected. If the crushed glass is properly sized and processed, it can exhibit the same properties apply to that of sand or gravel (Disfani et al, 2012).

2.7.2 Chemical composition and constituents of glass

Glass is a fused mixture of the silicates of alkalies, alkaline earth, and of more common metals. Usually, the alkaline bases are sodium and potassium; the alkaline earth is calcium, and the common metallic element is lead. All of these are used in the form of salts. In melting together, the various ingredients employed in the batch or mixture it appears that silica in the influence of heat in the presence of a flux forms silicates with sodium or potassium, and calcium, lead, etc. and the alkaline silicate then dissolves the remaining silicates. It is this solution that solidifies into the glass on cooling (Gautam et al, 2012). Sand is therefore, the major constituent of glass, constituting from 52 to 65 percent of the mass of the original mixture, or from 60 to 75 percent of the finished product after melting has driven off carbon dioxide, sulfur dioxide, and other volatile materials. Table 2.9 below shows the chemical composition of the glass (Gautam et al, 2012).

Table 2.9 The chemical composition of glass

Description	**Composition (% by mass)**
Silica (SiO2)	72.5
Alumina (Al2O3)	0.4
Iron oxide (Fe2O3)	0.2
Calcium oxide (CaO)	9.7
Magnesium oxide (MgO)	3.3
Sodium oxide	13.7
Potassium oxide	0.1
Loss on ignition	0.36

The raw materials used in manufacturing glass are sand, lime (chalks), and soda or potash which are fused over 1000°C. Oxides of iron, lead, and borax is added to modify hardness, brilliance, and color (Gautam et al, 2012).

The functions of the various ingredients are shown below (Du & Tan, 2014).

- ✓ Silica is used in the form of pure quartz, crushed sandstone, and pulverized flint; it should be free from iron contents for best quality glass. Since it melts at very high temperatures (1710°C) carbonates of sodium or potassium are added to lower down the fusing temperature to about 800°C.

- ✓ Lime is used in the form of limestone, chalk, or pure marble and sometimes marl. The addition of lime makes the glass fluid and suitable for blowing, drawing, rolling, pressing, or spinning. It also imparts durability and toughness to glass. Excess of lime makes the molten mass too thin for fabrication
- ✓ Soda acts as an accelerator for the fusion of glass and an excess of it is harmful
- ✓ Potash renders glass infusible and makes glass fire resistant.
- ✓ Lead oxide imparts color, brightness, and shine. When 15–30% of it added to substitute lime it lowers the melting point, imparts good workability.

2.8 The Effect of Alkali-Silica Reaction and Prevention Methods

2.8.1 The effect of alkali-silica reaction in concrete

Alkali silica reaction is a chemical reaction between certain reactive minerals in some aggregate and alkalies in the pore solution of concrete. This reaction can result in the expansion and cracking of concrete leading to shortened service life. It is a well-documented fact that combining glass aggregate with Portland cement may trigger ASR. What happens is the silica in the glass reacts with calcium hydroxide (a powerful alkali with PH of 12) in the Portland cement and forms a siliceous gel. This gel within the cement paste absorbs water and swells. If the swelling is sufficient the pressure can cause micro-cracking, expansion, and ultimately the deterioration of the surrounding concrete. Sometimes this happens early on, other times it can take years. The amount of damage inflicted by ASR on concrete depends on the volume and the particle size (Akhnoukh et al, 2016).

According to a report issued by the Clean Washington Center increasing the surface area to the ratio of glass (using smaller shards) will reduce the effect of reaction. Using smaller pieces of glass tends to speed up ASR, which gives the gel time to swell before the concrete hardens, and limiting potential damage. The powdered glass will be consumed by the process to the degree that it causes no ASR at all (PCA, 2011).

2.8.2 Alkali-Silica reaction Prevention method in concrete

There are a number of measures to avoid ASR or to mitigate its damaging. The following are prevention mechanisms of alkali-silica reaction in concrete (PCA, 2011).

A. Grinding the glass to pass at least U.S. standard mesh size no 50;

B. Adding mineral admixtures that can effectively suppress the reaction;

C. Using a low-alkali cement, which is likely to be less effective, unless alkalies from the environment can be kept away;

D. Developing special ASR-resistant cement, some of which are already being offered commercially.

2.9 Previous Products using Crushed Waste Glasses

Glass concrete products can be categorized as commodity products and value-added products. For simple commodity products, the primary objective is to utilize as much waste glass as possible. For value-added products, on the other hand, the esthetic potential of the glass is utilized, because glass can be very attractive. production of both commodity and value-added products requires a reliable supply of glass that is cleaned, crushed, and graded according to specifications. The crushing and grading operations ought to be coordinated such as to result in preferably zero wastage (Km et al., 2015). The following are types of products which are produced by partially replaced crushed waste glass in concrete.

2.9.1 Concrete Masonry

Block Unit: The first product to be developed for commercial production was a concrete masonry block unit. Because of the uncertainty at the time of project conception whether the solution of the ASR problem would be possible, a rather modest goal was set to replace just 10% of the fine aggregate with finely ground glass. The economics of concrete masonry block production is promising but depends strongly on a reliable supply of glass, that is cleaned, crushed, and graded according to specifications. Whereas replacing just the sand by finely ground glass may be of modest economic benefit, replacing also part of the cement by glass powder, which is obtained during the crushing process, improves the economic outlook (Km et al., 2015).

2.9.2 Paving Stone

The other product of glass is a paving stone, which contains up to 100% glass aggregate. The idea was to create a paver with novel colors and surface texture effects, such as special light reflections, that cannot be obtained with regular natural aggregate (Km et al., 2015).

2.9.3 Architectural and Decorative Concrete

Decorative concrete is the use of concrete as not simply a utilitarian medium for construction but as an aesthetic enhancement to a structure, while still serving its function as an integral part of the building itself such as floors, walls, and driveways. The most exciting applications appears be in the architectural and decorative fields. Not only can we engineer the materials mechanical and other properties to about any reasonable specifications. We can also create surface textures and appearances using techniques well known in the field of architectural concrete, while fully utilizing the esthetic potential of colored glass. The results can be stunning, and the numbers of potential applications are limited only by one's imagination. To name just a few building façade elements, precast wall panels, partition walls, floor tiles, wall tiles and panels, elevator paneling, tabletop counters, park benches, planters, trash receptacles and ashtrays (Km et al, 2015). The figure below shows different products produced by using crushed waste glasses.

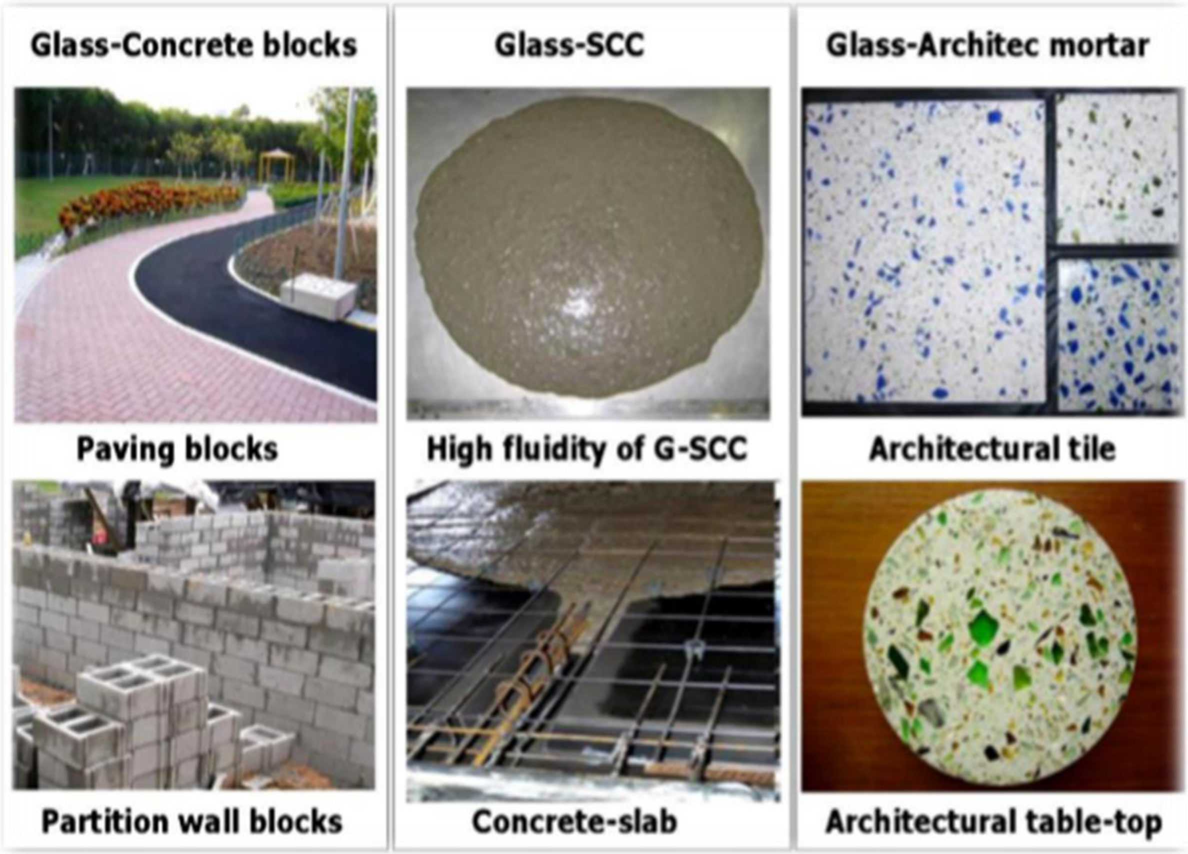

Figure 2.4 Potential glass of concrete products in construction industries (Source: Ling and Poon, 2011).

2.10 Previous Studies on Utilizing Crushed Waste Glass as Partial Replacement of Fine Aggregate

Different studies are carried out by using partial replacement of crushed waste glass in concrete as fine aggregate. The followings are some previous researches conducted.

The ground waste glass was used as fine aggregate in concrete and no reaction was detected with fine particle size, thus indicating the feasibility of the waste glass reuse as fine aggregate in concrete. In addition, waste glass seemed to positively contribute to the mortar micro-structural properties resulting in an evident improvement of its mechanical performance. Larger the particle size of waste glass more is the chance of ASR occurrence. It is reported that fine glass powder for incorporation into concrete up to 30% as a pozzolanic material suppressed the ASR. Hence the size of waste glass used in the range 01.18mm shows no effect of ASR (Adaway & Wang, 2015).

Fine aggregates were partially replaced by the waste glass at 10%, 20%, and 30% by weight. Concrete specimens were tested for compressive strength, splitting tensile strength, durability (water absorption), and lightweight nature for different waste glass percentages. The results obtained were compared with results of normal C-25 concrete mix and it was found that the maximum increase in compressive strength occurred for the concrete mix containing 20% waste glass as fine aggregate. With an increase in waste glass content, water absorption decreased indicating an increase in durability, An increase in compressive strength was observed up to 20% replacement of fine aggregates by the waste glass and thereafter decreasing (Sajad, 2013).

Partial replacement of fine aggregates with waste glass has with the increase in the Glass contents, the compressive strength increases up to 20% replacement and after that, it starts decreasing. The sample with a glass content of 20% shows the optimum results in comparison with the other samples this was reported by (Srivastava et al., 2009).

2.11 Literature Review Summary

The natural resources in the world are continuously decreasing due to the manufacturing of the products and their impact on the environment since disposing of the unwanted products is becoming issues that need to be addressed and resolved. This can be possible by adopting the policy of 3Rs; Reduce, Reuse, and Recycle.

In recent years, the rapid growth of the construction industry has led to environmental problems caused by excessive mining and usage of natural resources such as aggregate and cement. Extensive study efforts have been made to recycle wastes for possible use in the production of concrete products. among different types of material wastes crushed glass is one of them. Therefore, to make the construction industry sustainable and to solve the environmental problem reuse industrial waste products as an alternative material for concrete making should be devised. Among building construction materials hollow concrete block is one of them. The literature review addresses, the hollow concrete block production processes, physical requirements like; dimension and tolerance, density, water absorption, compressive strength, drying shrinkage, moisture content, a sampling of hollow concrete block criteria.

The literature review also addresses about glass such as the contribution of glass as partial replacement in concrete, the manufacturing processes, the classification, properties of crushed waste glasses and the effect of alkali-silica reaction with preventive method are discussed and also different types of products can be made from crushed waste glass are addressed, which are categorized as commodity products and value-added products. Among them concrete masonry block units, paving stones and architectural concrete can be mentioned. Previous studies show that crushed waste glass can be used as partial replacement of fine aggregate and as some of studies showed the optimal percentage replacement of fine aggregate using crushed waste glass is 20%. When the percentage replacement increases the compressive strength of the concrete will be decreased, however, 20% of crushed waste glass as a fine aggregate in a concrete enhancing the performance of the conventional concrete.

2.12 Gap Identification

It has been attempted to find out the utilization of crushed waste glass as a partial replacement of fine aggregate in concrete making materials, but according to the information from different construction stakeholders, there is no construction company, business center, or institution that utilized crushed waste glass for a conventional concrete or hollow concrete block. Most of the time waste glasses are dumped as garbage material despite their precious value for partial replacement of concrete ingredients. Generally, there is no practice in using crushed waste glass for the purpose of concrete block production in our country.

The researcher needs to fill the gap on previous studies which are mostly conducted using crushed waste glass as a partial replacement of cement, fine and coarse aggregate for structural concrete work. However, structural concrete work for a building such as column, beam and etc. require a huge amount of crushed waste glass and a research was conducted in Hawassa university by Kokeb (2019), on replacing crushed waste glass as a fine aggregate in C60 and C70 concrete, a high compressive strength concrete. But for this kind of concrete, replacement materials are not recommended because quality rather than cost is preferred and even the crushed waste glass may affect the durability of the structural elements. However, for production of hollow concrete blocks less amount of crushed waste glass per blocks is required; and this research is conducted for a non-load bearing block. Accordingly, the crushed waste glass does not affect the durability of the non-load bearing block; and has a limited application in the case of concrete structural components. So far there is no published research conducted in our country on using crushed waste glass as a partial replacement of fine aggregate in hollow concrete blocks. Therefore, this study focuses on the performance of class C hollow concrete block with crushed waste glass as a partial replacement of fine aggregate. Consequently, there is a gap in the utilization of this material for the purpose of value-addition in the production of hollow concrete block.

Hence, it is valuable to conduct an experimental study to fill the currently existing gap regarding utilization of crushed waste glass for concrete block making materials in a specified percentage. For this reason, this study was conducted to use this material which is regarded as waste for the purpose of class C hollow concrete block production.

CHAPTER 3

MATERIALS AND METHODS

3.1 General

The materials used for the investigation are described with respect to their sources and relevant physical and chemical properties using methods and procedure. The laboratory investigations such as the properties of the block making ingredients, density and water absorption tests was carried out in Hawassa university construction material laboratory, compressive strength tests in SNNPS construction Authority construction material laboratory, the production of the HCB was carried out in Elto concrete block production factory, Hawassa; and whereas the chemical composition of crushed waste glass is studied in Ethiopian Geological Survey, a center of Ethiopian Geo-science laboratory.

3.2 Study Design

3.2.1 Study type

The type of the study is experimental. To achieve the objectives of the study, the laboratory tests was conducted using different standards such as Ethiopian, and ASTM standards to evaluate the quality of the concrete block making ingredients and the performance of hollow concrete block.

3.2.2 Sampling size and selection techniques

The study adopted a purposive sampling selection process. For ingredients, a laboratory test was dependent on the types of test requirements and the result compared with different standards such as the Ethiopian standard, ASTM standard, and Indian Standards. For each test, quartering and weighting were used for sampling techniques. The purpose of the study was to determine the properties and performance hollow concrete block with and without crushed waste glass and to justify suitable percentages of replacement of fine aggregate with crushed waste glass. To determine the sample size of the test, it needs standards and specifications. According to ES 596:2001, a minimum of six samples is required for each test of the compressive strength of concrete block at each age.

The characteristic strength of concrete block is usually measured by using compressive strength using the compression test at a different age.

For the study, the compressive strength was tested at 7, 14 & 28 days, and for density and water absorption test were done at the age of 28 days. Generally, a total of 96 samples were used. Thirty (30 pieces) of them were produced without replacing sand by the crushed waste glass or they control analysis for the experimental study. The remaining number of blocks were produced by replacing sand by 10%, 20%, and 30% of crushed waste glass, six samples of the block were used for each percentage of replacement and control mix and also three samples for each percentage replacement of class C hollow concrete block were used for density and water absorption tests.

3.3 Sources of Data

Primary and secondary data have been used. Secondary data needed for this research have been collected from different journals, thesis, book, standards, website, etc. during the literature review and primary sources of data for this study were laboratory experimental output.

3.4 Method of Data Analysis

MS Excel 2013 and MS Word 2013 are used for the analysis, representation, and/or illustration of test results. After analysis of the test results, comparison and evaluation are derived to establish properties such as physical properties of concrete block ingredients and strength comparisons, and the like. Moreover, detected characteristics are observed, recorded, analyzed, and interpreted. After the data was analyzed, then it is presented by using tables, charts and graphs. Finally, conclusions are drawn and recommendations are forwarded based on the results and analysis of the experimental investigation and findings.

3.5 Materials

3.5.1 Cement

The type of cement used for the study is Ordinary Portland cement (OPC) produced as per CEM-I-42.5 grade contains 95 % clinker and 5 % gypsum produced by Dangote cement plc was used in the concrete block mixtures.

3.5.2 Fine aggregate

The fine aggregate used in this research was natural sand obtained from Langano lake around Ziway found in the Oromia region was used to prepare the concrete block samples.

3.5.3 Coarse aggregate

A coarse aggregate was supplied from crusher sites located at Hawassa city, known as "monopole site ". The maximum size of aggregate used was 10mm aggregate.

3.5.4 Water

Potable tap water was used for concrete block mixing and curing.

3.5.5 Crushed waste glass

The crushed waste glass material was obtained from waste dumping areas in Hawassa city around the diaspora site and from shop glasses. The waste glass primarily originated from pure and clear glass or plate glass which is used for such as window doors. The broken glass was cleaned to remove dirt materials and other impurities, the crushing activity was carried out manually with a hammer to get the required size and it was sieved with a series of sieves in the laboratory. Those crushed glass particles which pass through 4.75mm sieve and which retained on 150µm sieve were used for the study. It is similar to natural sand and exhibits properties of fine aggregate. The figure 3.2 below shows the procedures followed for CWG.

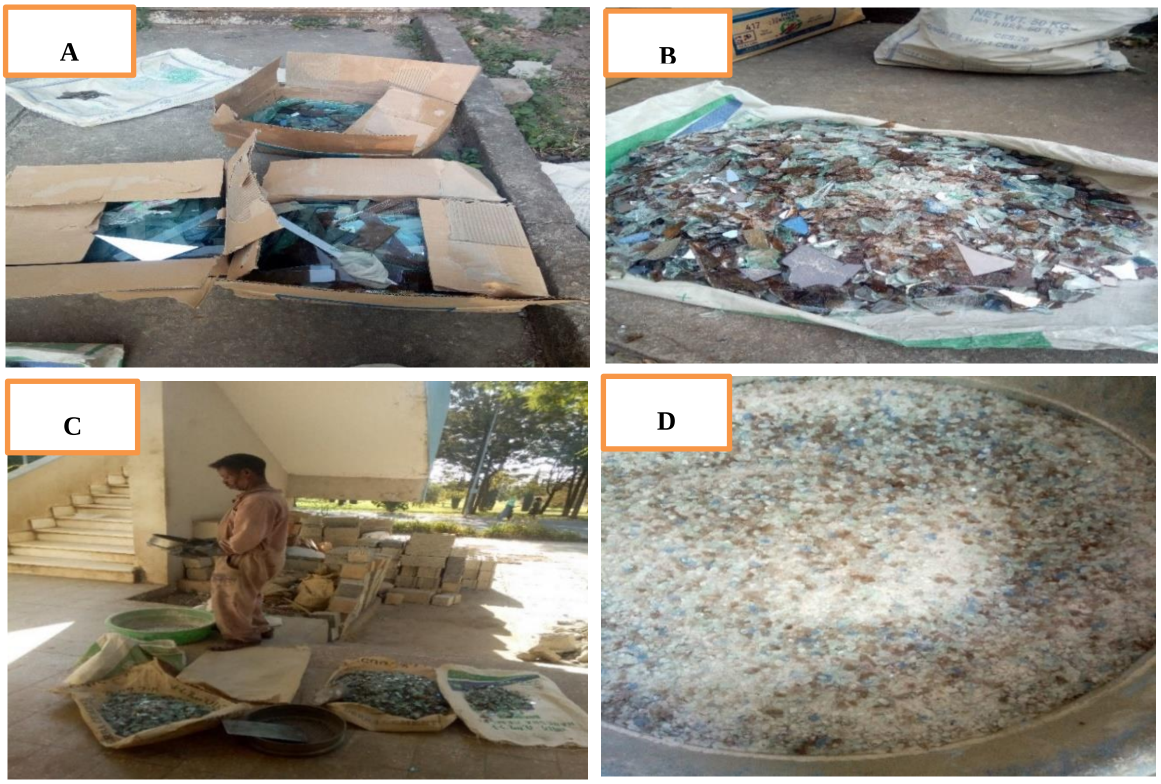

Figure 3.1 (A) CWG which are collected from waste dumping areas, (B) ready for crushing, (C) sieved by ASTM 4.75mm and (D) the sieved glass into the size of fine aggregate.

3.6 Equipment/Tools Used for Concrete Block Production

The equipment and tools used in this study are such as balance, oven-dry, shovel, specific gravity machine, sieve, measuring cylinder, block making machines, wooden plate, and compressive strength testing machine.

3.7 Tests

The methods employ in carrying out this research work are conducted through laboratory with respective tests for materials and specimens.

3.7.1 Fine aggregate

Laboratory tests conducted for fine aggregate were: silt content, sieve analysis, unit weight, specific gravity (bulk, apparent and SSD), water absorption, moisture content, and fineness modulus.

3.7.1.1 Silt content

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

Procedure for silt test (Dinku, 2002).

Take graduated cylinder or jar having a capacity of greater than 100ml, Pour 30ml of sand to the cylinder, Fill approximately % of the cylinder with water, Shake the cylinder vigorously for about a minute, Leave the cylinder for about an hour to allow the silt to settle on the layer of the sand and Measure the number of fines forming a separate layer on the top of the washed sand.

The percentage of silt in the total sand layer was calculated according to Equation 3.1

Silt content (%) = $\frac{A}{B} * 100$ ………………………………………………………… Eqn 3.1

Where: A = amount of silt deposited above the sand and

B = amount of clean sand

Figure 3.2 Silt content test for a fine aggregate

3.7.1.2 Sieve analysis for fine aggregate and crushed waste glass

The objective of the test is to determine the particle size distribution of fine aggregates and crushed waste glasses.

Procedure for grading fine aggregate (Dinku, 2002).

Weigh 2 kg of a sample of fine aggregates, Quarter the sample using a riffle box, From the quartered sample take 500gm, Weigh the empty sieves and record the data, Place the pan to the bottom of the sieve shaker and put the other sieves into the pan with increasing opening sizes of the sieves, Place the 500gm. of sample on the top of sieve (having large opening size), Shake the sample about 2 minutes in a sieve shaker, Weigh each sieve together with the aggregate retained on it, Calculate the weight retained on each sieve, Fill in the gradation chart below and compute the fineness modulus.

Table 3.1 The grading requirements for fine aggregates as per the ASTM standard.

Sieve Size	Percentage passing
9.50mm	100
4.75mm	95-100
2.36mm	80-100
1.18mm	50-85
600μm	25-60
300μm	10-30
150μm	2-10

Figure 3.3 The sieve samples of 500g (A) for fine aggregate and (B) for CWG

3.7.1.3 Fineness modulus of sand

Using the sieve analysis results, a numerical index called the fineness modulus (FM) is often computed according to equation 3.2.

$$FM = \sum \frac{Cummulative\ coarser(\%)}{100} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Eqn\ 3.2$$

Fine sand: F.M. 2.2 - 2.6, Medium Sand: F.M. 2.6 - 2.9, and Coarse Sand: F.M. 2.9 - 3.2

3.7.2 Moisture content test for fine aggregate and crushed waste glass.

The objective of this test is to determine the moisture content of fine aggregate, and crushed waste glass.

Procedure (Dinku, 2002).

Weigh a sample of 2kg coarse aggregate and 500gm fine aggregate separately (A), Oven dry the samples for about 24hrs with a temperature of 105 °c-110 °c, Remove the samples from the oven and place them on the desiccator for about an hour to cool without absorbing water from the atmosphere, Weigh the aggregates separately (oven-dry weight, B) and Calculate the moisture content of the aggregates. Separately calculated according to equation 3.3

$$W(\%) = \frac{A - B}{B} * 100 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Eqn\ 3.3$$

Where: w = Moisture content (%), $A = Weight\ of\ original\ sample\ (g)$,
B = $weight\ of\ the\ oven - dry\ sample\ (g)$

3.7.3 Specific gravity and absorption capacity of fine aggregate and CWG

The objective is to determine the bulk and apparent specific gravity, and absorption of fine aggregates, and crushed waste glass.

Procedure (Dinku, 2002).

Immediately introduce into the pycnometer 500.0g of the fine aggregate sample prepared and fill with water to approximately 90% of the capacity, Roll, invert and agitate the pycnometer to eliminate all air bubbles. Adjust its temperature to 23±1.7°C, if necessary, by immersion in circulating water and bring the water level in the pycnometer to its calibrated capacity, and Determine the total weight of the pycnometer, sample and water, and record.

C = 0.9976Va + 500 + W

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

Va =volume of water added to pycnometer, [cm3] and

W =weight of the pycnometer empty, [g]

Remove the fine aggregate from the pycnometer, dry to constant weight at a temperature of 1 05±5°C, cool in the air at room temperature for ½ to 1 ½ hrs, and weigh, Determine the weight of the pycnometer filled to its calibration capacity with water at 23±1.7°C.

B = 0.9976V + W

where: B = weight of flask filled with water, [g]

V = volume of flask, [cm3] and W= weight of the flask empty, [g]

Specific gravity and absorption capacity of fine aggregate and crushed glass calculated as equation below

$$\text{Bulk sp. gr} = \frac{A}{B + 500 - C} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots Eqn\ 3.4$$

$$\text{Bulk sp. gr. (saturated surface dry)} = \frac{500}{B + 500 - C} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots Eqn\ 3.5$$

$$\text{Apparent sp. gr} = \frac{A}{B + A - C} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots Eqn\ 3.6$$

$$\text{Absorption capacity (\%)} = \frac{500 - A}{A} * 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots Eqn\ 3.7$$

$where:$

$A\ =\ weight\ of\ oven - dry\ sample\ in\ air, [g]$

$B\ =\ weight\ of\ pycnometer\ filled\ with\ water, [g] and$

$C\ =\ weight\ of\ pycnometer\ with\ sample\ and\ water\ to\ calibration\ mark, [g]$

Figure 3.4 Specific gravity test A and B for fine aggregate, C and D for CWG

3.7.4 The class C hollow concrete block mix design

The cement, fine aggregate, coarse aggregate, crushed waste glass, and water were batched for Class C hollow concrete block according to proportion used in the production site because there is no standard proportion or ratios mix for a HCB in Ethiopia (Dinku,2004).

The fine aggregate was replaced with crushed waste glass by 10%, 20%, and 30% by Volume. Besides, the control mix was prepared without replacing fine aggregate with crushed waste glass. The class C hollow concrete block which is non-load bearing with size 20cm*20cm*40cm was prepared. Finally, Compressive strength, water absorption, and density tests were conducted. In this research, a proportioning of the blocks was prepared from the reference of Elto concrete block production factory which are utilized for production of non-load bearing hollow concrete blocks. The material used in this research for concrete block making are cement, sand, and 10mm aggregate with the ratio of 1:4:2 respectively and for replacement the same materials with crushed waste glass and ratios used except the ratio of sand are changed with the replacement percentages.

Table 3.2 Mix proportion for the control and replacement of class C HCB for this research

HCB Class C Percentage replacement	Block Size			Number of boxes (20cmx40cmx50cm) of material				Quantity of water (Liter)	Number of blocks produced per bag of cement (50kg)
	H	W	L	Cement	Sand	00 aggregate	Crushed glass		
0%				1	4	2	0	30	30
10%	20	20	40	1	3.6	2	0.4	30	30
20%				1	3.2	2	0.8	30	30
30%				1	2.8	2	1.2	30	30

3.7.5 The concrete block density test

According to Ethiopian standard ES 596:2001, 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 overall volume computed in cubic centimeters.

$$\text{Densiy} = \frac{\text{mass of the block in kg}}{volume\ of\ the\ specimen\ in\ cm3}\frac{10^6 kg}{m3} \ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots Eqn. 3.8$$

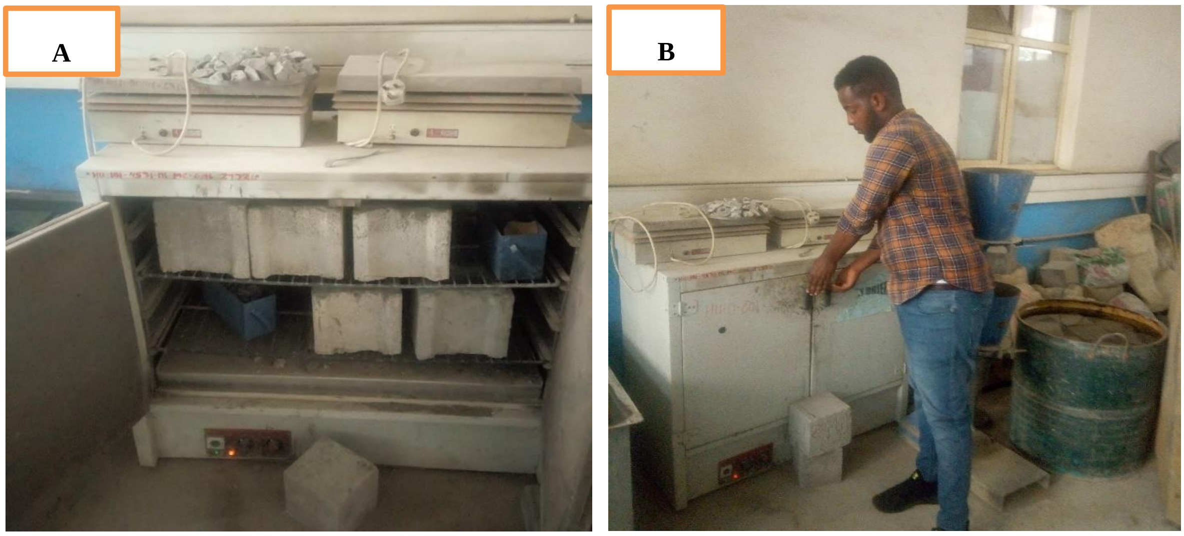

Figure 3.5 Density tests (A) Putting the samples in oven and (B) closed the oven dry for 24hrs

3.7.6 The concrete block water absorption test

Ethiopian standard [ES 596:2001], specifies water absorption 290 kg/m3 (25%) for load-bearing hollow concrete block and 320 kg/m3 (30%) for a non-load bearing hollow concrete block but Indian standard recommended 10 percent.

$$\text{Absorption} = \frac{A-B}{A-C} * 1000 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad Eqn\ 3.9$$

$where{:}\ \ A = Absorption, \% = \frac{A-B}{B} * 100,\ B = Dry\ mass\ of\ unit\ in\ Kg\ and$

$C = suspended\ immersed\ mass\ in\ Kg$

Figure 3.6 The water absorption tests (A) immersed in water and (B) suspended from water

3.7.7 The compressive strength test for concrete blocks

The objectives are to determine the compressive strength of concrete blocks. According to Ethiopian Standard hollow concrete blocks are classified into three: Class A, Class B and Class C. Class A and B, load-bearing units and Class C is non load-bearing units. This study was conducted for Class C non-loadbearing blocks, which is used for walls and partitions, and internal panels in steel-framed and reinforced concrete framed buildings(Dinku, 2002). According to ES, Minimum Compressive Strength for Classes C of hollow concrete block is an average of six units should be 2.0 N/mm2 and Individual units should be 1.8 N/mm2. For 0%, 10%, 20%, and 30% replacement percentages of crushed glass compressive strength tested at the ages of 7, 14, and 28 curing days.

Procedure for compressive strength test of hollow concrete block (Dinku, 2002).

1. Measure the dimensions of each block for a check.
2. Make the contact surfaces, with the testing machine, of each sample plane by capping with 1:1 mortar of 2 to 3mm thickness. The caps shall be aged for at least 24 hours before the samples are tested
3. Place each sample in a position such that the load is applied in the same direction as in service and the sample is centralized between the pressure surfaces.
4. Increase the compressive force at the rate of 0.2 to 0.5 N/mm2s (2 to 5 kgf/cm2s) until the sample breaks.
5. Record the maximum load (load at rupture).

The values of the compressive strength of each block unit were computed as follow;

$$\text{Compressive strength, MPa} = \frac{Failure\ load}{Effective\ area} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3.10$$

The blocks were used for this study have contained three holes; in which two of them are equal and arranged at the end, and the third hole which has a smaller dimension is located in the middle. The detailing for dimensions is described in figure 3.8.

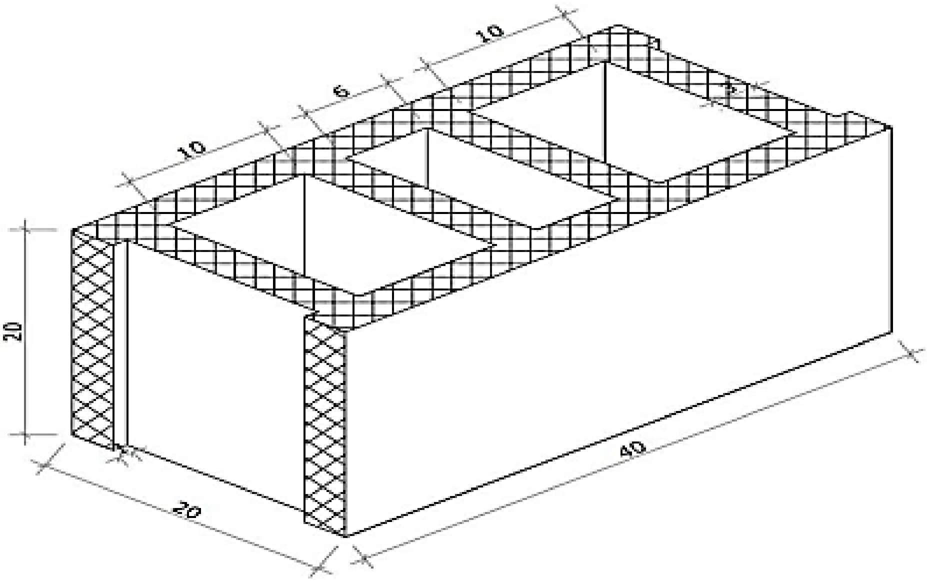

Figure 3.7 The details dimension for hollow concrete blocks produced in this study [in cm]

Where; Effective area = Gross area (A gross) – Area of holes (A-holes).

Thus, Gross area = 20cm x 40cm = 800cm^2

Area of holes = ((14cm x 6cm) + (2 x ((14cm x 1cm) + (14cm x 10cm))) = 392cm^2

Effective area = (800 – 392) cm^2 = 408cm^2 (the area which is used to compute the compressive strength of blocks).

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

This section presents the results and discussions of tests carried out on performance of class C hollow concrete block with crushed waste glass as partial replacement of fine aggregate. The experimental results are described with the help of tables, charts, and graphs and also discussed by comparing with the controlled specimens, reference standards (or specification) and other previous related researches. In this part of the study, the properties of fine aggregate and crushed waste glass such as silt content for sand, sieve analysis, moisture content, specific gravity, absorption capacity, and the performance of class C HCB with and without replacement of CWG test results such as density, water absorption, compressive strength and also cost comparison of concrete block are presented.

4.2 The Physical Properties of Fine Aggregate and Crushed Waste Glass

4.2.1 Silt content

According to ES standard, the average silt content of the sand used for the mix is determined using Equation 3.1

$$\text{Silt content }(\%) = \frac{A}{B} * 100, \text{ Silt content }(\%) = \frac{4ml}{130ml} * 100 = 3.1\%$$

The material in fine aggregates which is finer than 75µm is generally regarded as silt. The presence of dust, loam, and clay materials in sand decreases the bond between the materials to be bound together thereby decreases the strength of concrete besides decreasing the quality of concrete block. From the silt content test performed on the sand, 3.1 % of silt was identified. According to the Ethiopian standard, it is recommended to wash the sand or reject if the silt content exceeds a value of 6 %. However, the test result obtained 3.1 % of silt, which is lower than the allowable limit of 6% therefore, it complies with the Ethiopian standard.

4.2.2 Sieve analysis

The Sieve Analysis used to determine the particle size distribution. The sieve analysis was carried out by following the ASTM C 33 Standard.

4.2.2.1 Sieve analysis for fine aggregate

The gradation test results of the fine aggregate are tabulated in tables 4.1, and the graphical representation is shown in figure 4.1 below, with the grading limits known to meet the requirements discussed previously in tables 3.1. The fineness modulus was calculated using Equation 3.2.

Table 4.1 The grain size distribution of fine aggregate

Sieve Size	Weight of sieve (g)	Weight sieve & Retained (g)	Weight Retained (g)	Percentage Retained (g)	Cumulative coarser (%)	Cumulative passing (%)	Standard limit (%)
9.50mm	490	490	0	0	0	100	100
4.75mm	410	420	10	2	2	98	95-100
2.36mm	460	470	10	2	4	96	80-100
1.18mm	450	520	70	14	18	82	50-85
600µm	410	630	220	44	62	38	25-60
300µm	370	500	130	26	88	12	10-30
150µm	270	310	40	8	96	4	2-10
Pan	550	570	20	4	100	0	--
	Total		500	100	270		
Finesse Modules =$\sum$ cumulative coarser (%)/100 =270/100 = 2.7							

The grading curve for the sieve analysis of fine aggregate and the standard (ASTM C33) is shown in figure below.

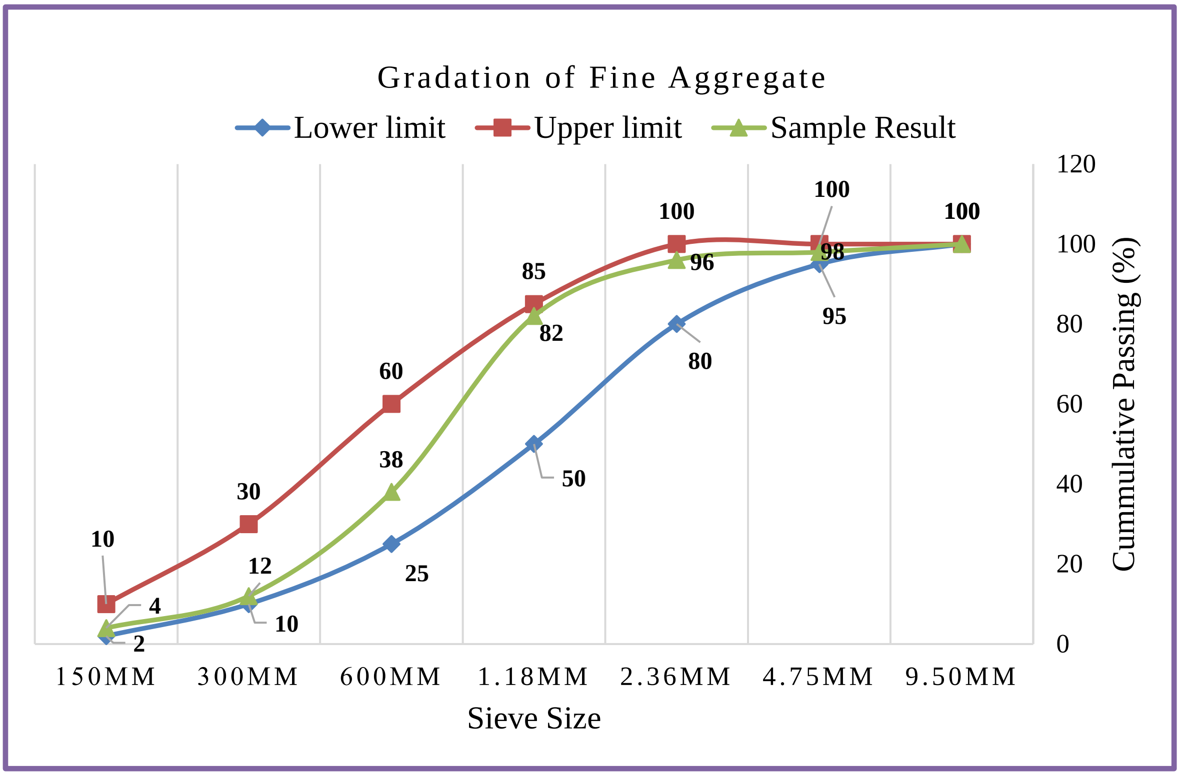

Figure 4.1 Fine aggregate gradation curve

Sieve analysis is the process of dividing a sample of aggregate into a fraction of the same particle size, used to determine the grading or size distribution of the aggregate. Grading of a sample of aggregate is used to determine whether or not a particular grading is suitable to produce good concrete, grading is important as far as it affects the workability because strength is dependent of grading.

From the above table 4.1 and figure 4.1 we can see that the sieve analysis test result shows that the cumulative percent passing is within the standard limit. The test result of each sieve number complies with the standard which means the fine aggregate used for this study is fulfills the requirements as per the ASTM C 33 standard. The fineness modulus of fine aggregate used in this research was calculated as 2.7, which is within the specified range of medium sand between 2.6 – 2.9 fineness modules value by the ASTM standard.

4.2.2.2 Sieve analysis for the crushed waste glass

The gradation test results of the crushed waste glass aggregate are tabulated in tables 4.2, and the graphical representation is shown in figure 4.2 below, with the grading limits known to meet the requirements discussed for fine aggregate previously in tables 3.1 because the crushed waste glass used for replacement should have to meet the requirements of fine aggregate gradation set as per ASTM C 33 standard. The fineness modulus was calculated using equation 3.2.

Table 4.2 The grain size distribution of crushed waste glass

Sieve Size	Weight of sieve (g)	Weight sieve & Retained (g)	Weight Retained (g)	Percentage Retained (g)	Cumulative coarser (%)	Cumulative passing (%)	Standard limit (%)
9.50mm	490	490	0	0	0	100	100
4.75mm	410	430	20	4	4	96	95-100
2.36mm	460	490	30	6	10	90	80-100
1.18mm	450	500	50	10	20	80	50-85
600μm	410	680	270	54	74	26	25-60
300μm	370	420	50	10	84	16	10-30
150μm	270	310	40	8	92	8	2-10
Pan	550	590	40	8	100	0	--
	Total		500	100	284		
Finesse Modules =∑ cumulative coarser (%)/100 =284/100 = 2.84							

The grading curve for the sieve analysis of crushed waste glass and the standard (ASTM C33) is shown in the figure below.

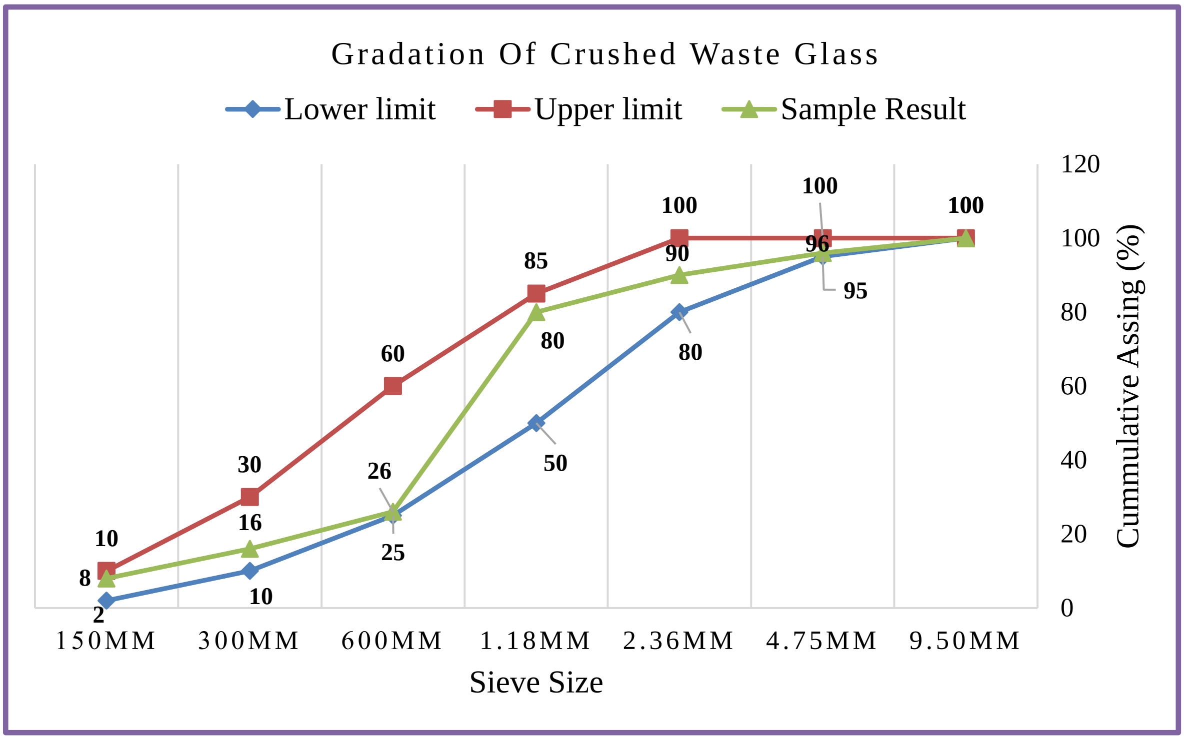

Figure 4.2 The crushed waste glass gradation curve

From the above Table 4.2 and figure 4.2 we can see that the sieve analysis test result shows that the cumulative percent passing is within the standard limit for fine aggregate. Therefore, the crushed waste glass has fulfilled the requirements of fine aggregate as per the ASTM C 33 standard.

The fineness modulus of the crushed waste glass was calculated as 2.84, which is within the specified range of medium sand between 2.6 – 2.9 fineness modules value by the ASTM standard. In general, the fineness modules result of both fine aggregate and crushed waste glass are categorized in medium sand, fine aggregate with a very high or low for fineness modules will not be as good for concrete aggregate as medium sand because, the coarser aggregate may not be workable, and fine sands are uneconomical.

4.2.3 Specific gravity and absorption capacity of fine aggregate and CWG

The specific gravity of fine aggregate and crushed waste glass test results was calculated using equation 3.5, 3.6, 3.7, and 3.8 are shown in table 4.3 below.

Table 4.3 Specific gravity and absorption capacity for fine aggregate and crushed glass

Properties	The fine aggregate test result	The Crushed glass test result
Weight of original sample, (g) = 500	500	500
Weight of oven-dry sample in the air [A], (g)	490	500
Weight of pycnometer + water [B], (g)	1317.6	1317.6
Weight of pycnometer + sample + water [C]	1618	1618
$\text{Bulk sp. gr } = \frac{A}{B+500-C}$	2.50	2.3
$\text{Bulk sp. gr. (saturated surface dry)} = \frac{500}{B+500-C}$	2.58	2.27
$\text{Apparente specific gtavity } = \frac{A}{B+A-c}$	2.66	2.27
$\text{Absorption capacity (\%)} = \frac{500-A}{A} * 100$	2.04	0

From table 4.3 above the properties of fine aggregate and crushed waste glass test results shows the bulk specific gravity of fine aggregate has 2.5 and crushed waste glass has 2.3 this means the specific gravity of fine aggregate has greater than crushed waste glass, which means the crushed waste glass has lightweight than the sand, this have numerous advantages such as reduce the weight of concrete block which means reduces the deadload of the structure and may solve the durability of structural problem caused due to the weight of the blocks. The water absorption capacity of the sand has 2.04% and the crushed waste glass has 0%, this is due to glass has impermeable or waterproof.

4.2.4 The crushed waste glass complete silicate analysis results

The crushed waste glass complete silicate analysis test results carried out in Ethiopia geological survey, Geochemical laboratory to obtain the chemical compositions of the crushed glass by taking 500gm of sample to analyze the complete silicate. Table 4.4 below shows that the complete silicate analysis results of crushed waste glass used in this study.

Table 4.4 The chemical composition of crushed waste glass using complete silicate analysis

Chemical Composition	A test result of crushed waste glass percentage by weight	Chemical Composition	A test result of crushed waste glass percentage by weight
SiO2	71.66	K2O	0.52
Al2O3	<0.01	MnO	0.04
Fe2O3	0.28	P2O5	0.05
CaO	10.34	TiO2	0.03
MgO	3.76	H2O	0.08
Na2O	14.18	LOI	0.25

The chemical compositions of river sand have Silicon dioxide (SiO2), Aluminum oxide (Al2O3), Iron oxide (Fe2O3), Calcium oxide (CaO), Magnesium oxide (MgO), Sodium oxide (Na2O), Potassium oxide (K2O), Titanium oxide (TiO2), and etc. From those chemical compositions of sand more than 70% has Silicon dioxide (SiO2) which is abundantly available in river sand. Glass is produced from three main ingredients which are sand, soda ash, and limestone. From the table 4.4 above shows the crushed waste glass complete silicate analysis results obtained more than 70% was silicon dioxide (SiO2), which is abundantly available in the crushed glass therefore, this shows that in some existent the glass has similar chemical composition with sand so, it can replace sand partially in concrete block.

The performance of class C hollow concrete block with crushed waste glass as partial replacement of fine aggregate using density, water absorption, and compressive strength tests.

4.3 The Density Tests

The blocks weighed in gram and the density of each block was calculated using the following equation [Eq. 3.8] and the result is shown in table 4.5.

Table 4.5 The average density test results for class C HCB

Class of HCB	Percent replacement [%]	Test age [days]	Dimension [cm3]	Weight before oven-dry [kg]	Weight after oven-dry [kg]	The average dry density of produced block [kg/m3]
Class C	0	28	15800	16.00	15.90	1006.33
	10	28	16000	15.90	15.70	981.25
	20	28	16000	15.80	15.50	968.75
	30	28	16000	15.60	15.20	950

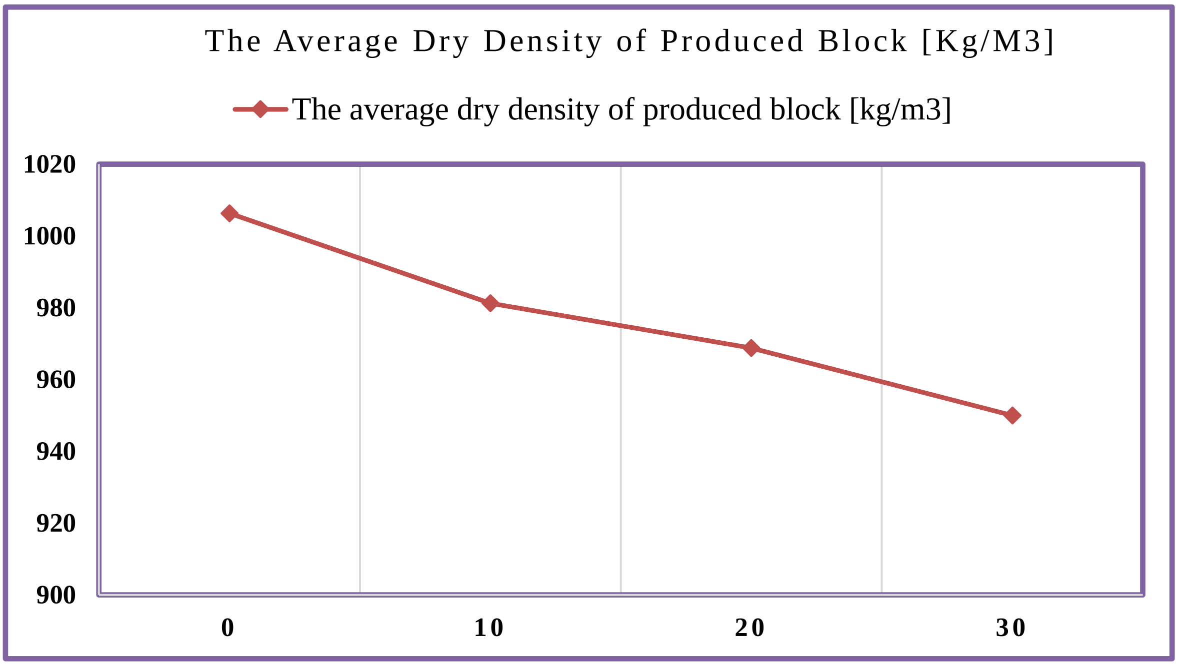

Figure 4.3 The average dry density results at 28 days of class C HCB

In this experiment, the density of hollow concrete block class C, size 20x20x40 cm at the 28days, substitution of fine aggregate by crushed waste glass the result of the specimens 0%,10%, 20%, and 30% replacement are 1006.33, 981.25, 968.75, and 950 Kg/m^3 respectively.

The density of class C hollow concrete block compared to the control mix with partially replaced specimen it decreased as the proportion of crushed waste glass increases and decreased by 2.49% at a 10%, 3.73% at a 20%, and 5.6% at a 30% replacement level. According to the Ethiopian standard [ES 596:2001], the density of concrete block for class C Non-loadbearing is between 900 kg/m^3-1200 kg/m^3. As the experimental result shows all specimen are within the limit of the density requirement set by the Ethiopian standard.

For a hollow concrete block, low density is probably the most characteristic feature. Besides, it depends primarily on the aggregate density and the proportions of the aggregate because the particle density of individual grading fraction can differ considerably and thus will affect the density of the concrete block. This property also influenced by the cement, aggregate, water, and air contents, the test results shows that the density of blocks decreases with replacement percent increases, due to density of crushed waste glass is less than the density of natural fine aggregate this implies the block produced using crushed waste glass is lightweight than the conventional once. this have numerous advantages such as reduction in dead loads, stiffness, strength, structural stability, it is easy and quick to install on site, lower hauling and handling costs and the like.

When incorporation of crushed glass increases in percentage of replacement was found to cause a slight reduction in the density of concrete blocks, as reported in a few works such as (Ling et al., 2014), (Chen et al., 2018), and (Srivastava et al., 2009). This is mainly due to the lower density of crushed glass compared to conventional aggregates.

4.4 The Water Absorption Tests

The water absorption test results for Hollow concrete block class C mixes at 28 age days are presented in Table 4.6 and Figure 4.4.

Table 4.6 The average water absorption of class C HCB

Class of HCB	Percent replacement [%]	Test age [days]	Dimension [cm] H	W	L	Weight after removal from water and dried for one min.[kg] [A]	Weight before immersed into water [kg] [B]	Percent absorption $\frac{A-B}{B}*100$ [%]
Class C	0	28	20	20	40	16.30	15.50	5.16
	10	28	20	20	40	15.90	15.20	4.61
	20	28	20	20	40	15.60	15.00	4.00
	30	28	20	20	40	15.40	15.00	2.66

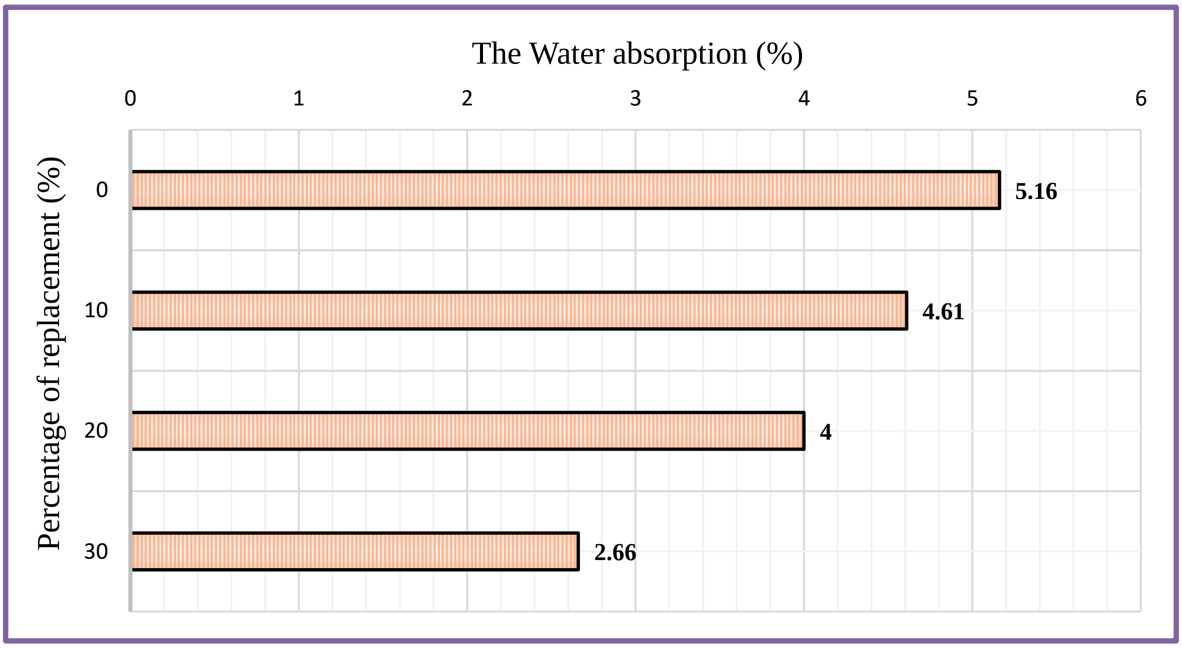

Figure 4.4 The water absorption results at 28 days of class C HCB.

In this experiment, the water absorption of class C hollow concrete block, size 20x20x40 cm at the 28 days, the substitution of fine aggregate by the crushed waste glass the result of the specimens 0%,10%, 20%, and 30% replacement are 5.16%, 4.61%, 4%, and 2.66% respectively.

The water absorption of class C hollow concrete block compared to the control mix with partially replaced specimen it decreases as crushed waste glass content increases and decreased by 0.55% at a 10%, 1.16% at a 20%, and 2.5% at a 30% replacement level.
According to Ethiopian standard [ES 596:2001] specify water absorption 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 fine aggregate by the crushed waste glass for class C size 20 cm x 20 cm x 40 cm hollow concrete block specimens, the test results in table 4.7 shows that water absorption with crushed waste glass is within the limit of the recommended value which means that it satisfies the requirements of the Ethiopian standard.

The test results showed that increase the percentage of the crushed waste glass in mixes lead to decreasing the water absorption as compared with the controlled mix. This is due to the recurring that the continuous hydration process will produce concrete with lower porosity. As hydration products fill the pore between cement particle and aggregate to reduce the average pore diameter. On the other hand, this is mainly due to the behavior of glass is attributed to the hydrophobic or impermeable nature which means glass has able to resist the penetration of water and also zero water absorption compared with natural fine aggregates. This reduction in water absorption with increase percentages replacement indicates better performance of glass blended with fine aggregate in concrete block over the conventional concrete block. Since crushed glass particles have a smaller water absorption value than the natural fine aggregates, so that replacing of crushed waste glass with fine aggregate would lead to the concrete block water absorption decrease. The advantages of decreasing water absorption in concrete block are linear shrinkage and water absorption pose no problems because of the water absorption of glass is zero and the other advantages is an excellent abrasion resistance that can be reached only with few natural stone aggregates due to the high hardness of glass. A similar observation was reported by Otunyo & Okechukwu, (2017), (Nishikant et al., 2016), and (Srivastava et al., 2009).

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4.5 The Compressive Strength Tests

The compressive strengths of the controlled and waste glass concrete mix at 7, 14, and 28 days are presented in table 4.7, 4.8, and 4.9 respectively. The comparison between the values of the compressive strength for the same mixes is shown in figure 4.5, 4.6, and 4.7 respectively.

Table 4.7 The average compressive strength at 7 days of class C HCB

Percentage of replacement (%)	Dimension (cm^2)			Effective Area (cm^2)	Failure load (KN)	Compressive strength (MPa)
	L	W	H			
0	40	20	20	408	39.78	0.97
10	40	20	20	408	51.25	1.25
20	40	20	20	408	52.21	1.28
30	40	20	20	408	45.30	1.11

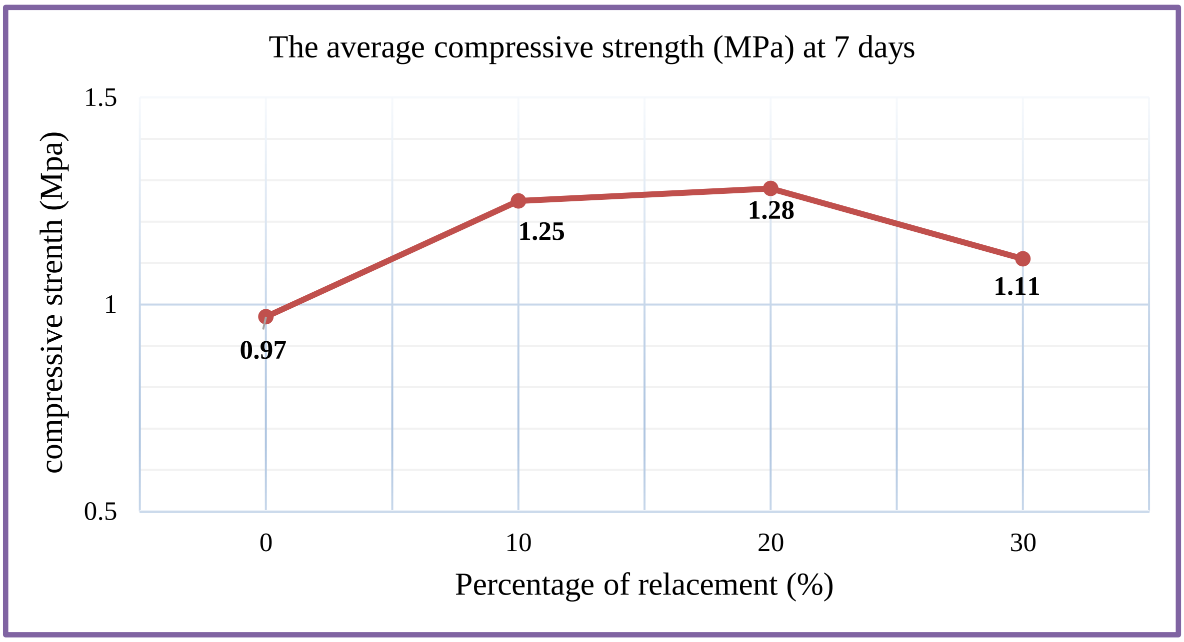

Figure 4.5 The average compressive strength at 7 days of class C HCB

Table 4.8 The average compressive strength at 14 days of class C HCB

Percentage of replacement (%)	Dimension (cm^2)			Effective Area (cm^2)	Failure load (KN)	Compressive strength (MPa)
	L	W	H			
0	40	20	20	408	68.90	1.68
10	40	20	20	408	88.91	2.15
20	40	20	20	408	100.30	2.46
30	40	20	20	408	64.10	1.56

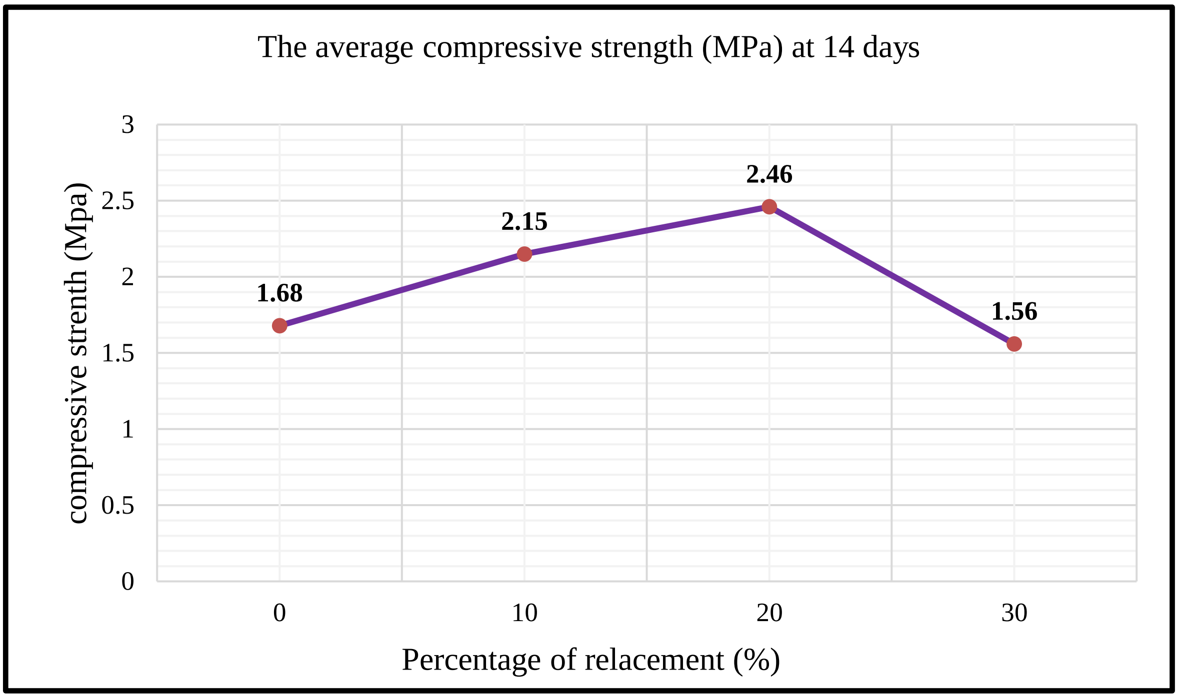

Figure 4.6 The average compressive strength at 14 days of class C HCB

Table 4.9 The average compressive strength at 28 days of class C HCB

Percentage replacement (%)	Dimension (cm^2)			Effective Area(cm^2)	Failure load (KN)	Compressive strength (MPa)
	L	W	H			
0	40	20	20	408	88.33	2.16
10	40	20	20	408	107.01	2.63
20	40	20	20	408	140.88	3.45
30	40	20	20	408	79.11	1.93

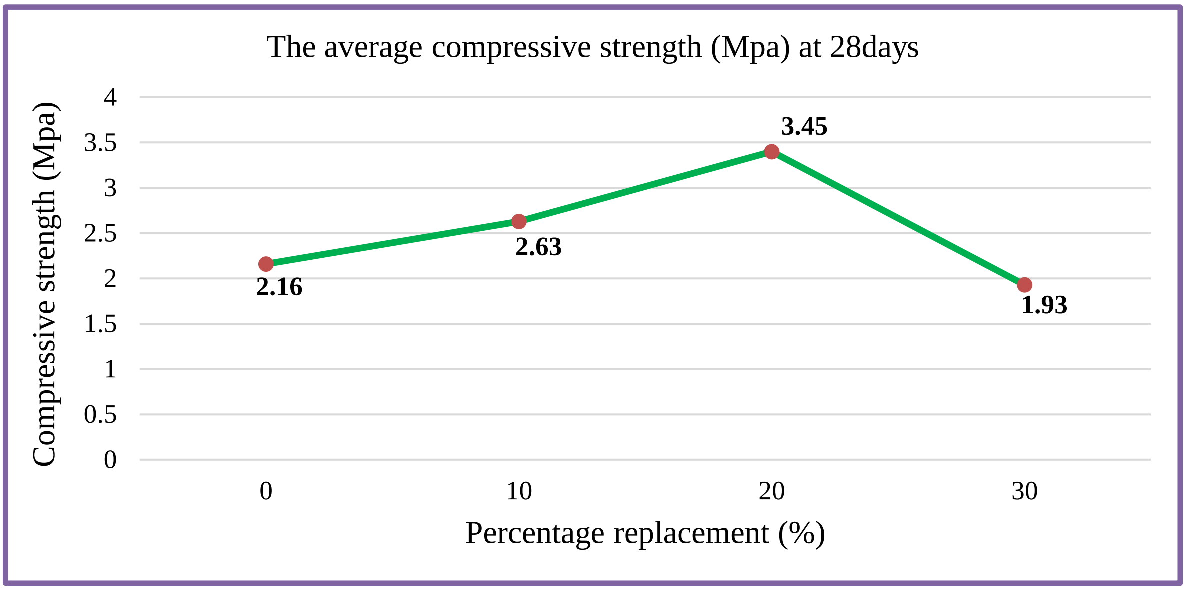

Figure 4.7 The average compressive strength at 28 days of class C HCB

In this experiment, the compressive strength of hollow concrete block class C, size 20x20x40 cm at the 7, 14, and 28 days, the substitution of fine aggregate by the crushed waste glass at 28days the result of the specimens 0%, 10%, 20%, and 30% replacement are 2.16, 2.63, 3.45, and 1.93 MPa respectively.

The average value recorded from compressive strength tests carried out on specimens cured for 7 days can be seen in figure 4.5 above. An increasing trend can be witnessed along with the addition of glass aggregate until the maximum compressive strength (1.28 MPa) was developed at a replacement level of 20%. The results of compressive strength tests following 14 days of curing can be seen in figure 4.6 above. The results closely mirror that of the seven-day test, with the compressive strength following an increasing trend with the addition of waste glass up until maximum compressive strength (2.46 MPa) was developed at a replacement percentage of 20%. The results of compressive strength tests following 28 days of curing can be seen in figure 4.7 above. The results closely mirror that of the fourteen-day test, with the compressive strength following an increasing trend with the addition of waste glass until maximum compressive strength was developed at a replacement percentage of 20%. At this replacement level, the maximum compressive strength developed was 3.45MPa, which was higher than that achieved by the control mix 2.16 MPa and it increased by 59.72%. The specimen containing 30% crushed waste glass was found to have achieved a compressive strength of 1.93 MPa at 28days, which means lower than that achieved by the control mix 2.16 MPa and it decreased by 10.64%.

According to Ethiopian standard the minimum average compressive strength for hollow concrete block class C is 2 MPa. As the experiment the compressive strength result showed that a partial replacement of the crushed glass with fine aggregate up to 20% was 3.45MPa which is within the limit therefore, it satisfies the recommended value set by the Ethiopian standard. The increase in strength above that of the control mix may be attributed to the angular nature of the glass aggregate, which have a greater surface area and higher interlocking tendency than the naturally rounded sand particles. This increased surface area allows for greater bonding with the cement paste, resulting in a stronger concrete matrix. These findings support earlier research conducted by Turgut & Yahlizade, (2009).

All controlled and glass aggregate mixes showed a continuous increase in strength with age except 30% replacement increase slowly and also decrease at 28 days compared to the control mix and other replacement percentages. It can be observed that the inclusion of glass as fine aggregate replacement lowers the compressive strength of concrete blocks, particularly at 30% replacement levels. This was due to incorporated crushed waste glass above the required amount in the concrete block. which attributed to the decrease in aggregate-cement bond caused by smooth and impermeable surface of the glass particles. A similar observation was reported **(**Ling et al., (2014), Additionally, Chen et al., (2018) suggested that uses of more amount of crushed glass could reduce the compactness and subsequently the strength of concrete blocks.

4.6 The Optimal Replacement of Crushed Waste Glass

The other objective of this research was to determine the optimum percentage of replacement at which crushed waste glass can be effectively put into service in class C hollow concrete blocks production.

As the experiment, the results showed the minimum average compressive strength of class C hollow concrete block with up to 20% of crushed waste glass replaced fine aggregate was 3.45 MPa which has the optimum compressive strength compared to the control mix and other replacement percentages and satisfy the minimum average compressive strength limit for class C non-loadbearing block according to the Ethiopian standard and this 20% replacement as discussed previously the density and water absorption test results showed it satisfies the recommended value set by Ethiopian standards. However, 30% replacement of crushed waste glass has satisfied the limit of Ethiopian standard by density and water absorption tests but, by compressive strength test it has not fulfilled the recommended value of minimum compressive strength. Therefore, the performance of class C hollow concrete block with up to 20% of crushed waste glass replaced fine aggregate can be effectively put into service**.**

This was similarly reflected in the research by Turgut & Yahlizade, (2009) and (Srivastava et al., 2009). whereby the inclusion of 20% crushed glass as a fine aggregate replacement was found that optimum percentage of the compressive strength of the concrete blocks.

4.7 Economic Feasibility

The final objective of this study was to compared the cost of class C hollow concrete block with optimal replacement of fine aggregate by crushed waste glass and that of conventional once.

Table 4.10 Material cost comparisons of the conventional and crushed waste glass block.

Material Costs							
Conventional hollow concrete block				Hollow concrete block with crushed glass			
No	Item name	Quantity per 1m^2 of HCB wall area	Cost per 1m^2 of HCB wall	No	Item name	Quantity per 1m^2 of HCB wall area	Cost per 1m^2 of HCB wall
1	Cement	20.84kg	72.91birr	1	Cement	20.84kg	72.91birr
2	Sand	116.14kg	15.12birr	2	Sand	85.71kg	10.71birr
3	00 aggregate	53.6kg	6.1birr	3	00 aggregate	53.6kg	6.1birr
4	Water	15lit	1birr	4	Crushed glass	12.56kg	0birr
				5	Water	15lit	1lit
	Total cost of material per 1m^2 of HCB wall		95.13birr		Total cost of material per 1m^2 of HCB wall		90.72birr

The above table 4.10 shows the material cost comparisons of the conventional and 20% of crushed waste glass class C hollow concrete blocks. The types of materials use for the Conventional and crushed waste glass concrete block are the same, except glass. Total cost of material per 1m^2 area of the conventional class C HCB wall is 95.13birr and total cost of materials per 1m^2 area of class C HCB with 20% of crushed waste glass is 90.72birr which is less than that of the conventional block due to the crushed waste glass material is obtained free cost. This is uses in reducing the amount of fine aggregate needed for production of class C HCB and also reduces the cost withdrawal for fine aggregate.

Table 4.11 The labor cost comparisons of the conventional and crushed waste glass block.

Labor Costs							
Conventional hollow concrete block				**Hollow concrete block with crushed glass**			
No	labor	Number of crew per $1m^2$ of HCB wall	Cost per $1m^2$ of HCB wall	No	labor	Number of crew per $1m^2$ of HCB wall	Cost per $1m^2$ of HCB wall
1	Concrete making	2	16.67birr	1	Concrete making	2	16.67birr
2	Operator	1	8.33birr	2	Operator	1	8.33birr
				3	Waste glass collector and crusher	3	1.50birr
	Total cost of labor per $1m^2$ of HCB wall		25birr		Total cost of labor per $1m^2$ of HCB wall		26.50birr

The above table 4.11 shows the labor cost comparisons of the conventional and crushed waste glass block. The types of labor and number of crew required for Conventional concrete block are varies depending up on the production capacity or firms however, usually uses two concrete making and one operator. For hollow concrete block with crushed waste glass the types of the labor required is the same as the conventional once, except there are additional labor needs such as waste collector and crusher. Total cost of labor for conventional class C HCB per $1m^2$ area is 25birr and for class C HCB with 20% crushed waste glass is 26.50birr. The result of comparisons showed the labor cost Per $1m^2$ area of class C HCB with 20% crushed waste glass has greater than the Conventional hollow concrete block due to additional labors are required for production of the blocks. for hollow concrete block production using crushed waste glass such as waste glass collector and crusher.

Table 4.12 Equipment cost comparisons of the conventional and crushed waste glass block.

Equipment Costs							
Conventional hollow concrete block				**Hollow concrete block with crushed glass**			
No	Equipment and tools	Quantity per $1m^2$ of HCB wall area	Cost per $1m^2$ of HCB wall	No	Item name	Quantity per $1m^2$ of HCB wall area	Cost per $1m^2$ of HCB wall
1	Hand operated equipment	1	0.25c	1	Hand operated equipment	1	0.25c
2	Masonry tool	1	0.25c	2	Glass crusher	1	0.5c
3	Manual mold	1	0.25c	3	Masonry tools	1	0.25c
4	Pallet	13	0.25c	4	Manual mold	1	0.25c
				5	Pallet	13	0.25c
	Total cost of equipment per $1m^2$ of HCB wall		1birr		Total cost of equipment per $1m^2$ of HCB wall		1.5birr

The above table 4.12 shows the equipment cost comparisons of the conventional and crushed waste glass block. The types of equipment required for Conventional concrete block are varies depending up on the production capacity or firms. However, usually for the conventional block uses hand operated equipment, masonry tools, manual mold, and pallet and also the same equipment is uses for 20% of crushed waste glass in class C hollow concrete block production, except the glass crusher equipment.

Total cost of equipment per $1m^2$ of conventional class C HCB wall is 1birr and total cost of equipment per $1m^2$ area of class C HCB with 20% of crushed waste glass is 1.50birr. The comparisons result showed the cost of equipment per $1m^2$ area of class C HCB with crushed glass has greater than that of the Conventional once due to additional equipment is required which is glass crusher.

Generally, the cost comparison of class C hollow concrete block with and without crushed waste glass are discussed as the followings:

The direct cost of conventional class C HCB = Material cost + labor cost + Equipment cost

The direct cost of conventional class C HCB in $1m^2$ area = 95.13 + 25 + 1 = 121.13birr

Number of HCB required in $1m^2$ area = 12.5 HCB

Therefore, the cost of one block of conventional HCB = 121.13/12.5 ≈ 9.70birr

The direct cost of class C HCB with 20% replacement of fine aggregate by crushed waste glass are = Material costs + labor costs + Equipment costs = 90.72 + 26.5 + 1.5 = 118.72birr

Number of HCB required in $1m^2$ area= 12.5 HCB

The cost of one block produced with 20% crushed waste glass = 118.72/12.5 ≈ 9.50 birr

The cost of conventional class C HCB per block is 9.70birr and for class C HCB with crushed waste glass per block is 9.50birr this shows the cost of class C HCB with 20% of crushed waste glass is less production cost than the conventional concrete block and it decreased by 2.06% in $1m^2$ area. Therefore, class C hollow concrete block with crushed waste glass as partial replacement of fine aggregate up to 20% is economically feasible compared to the conventional once.

Note: The cost benefit analysis such as material and labor costs were calculated depending upon market costs in Hawassa city on April, 2020, the calculations and the costs attached on appendix E.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

In this research, the performance of hollow concrete blocks with partial replacement of crushed waste glass as fine aggregates has been studied. The experimental works are carried out to evaluate the properties and performances of hollow concrete blocks. Based on test results obtained by density, water absorption, compressive strength, and also cost compression of hollow concrete blocks. Based on finding the following conclusions are drawn.

1. The density of class C hollow concrete block compared to the control mix with partially replaced specimen it decreased as the proportion of crushed waste glass increases and decreased by 2.49% at a 10%, 3.73% at a 20%, and 5.6% at a 30% replacement level.
2. The water absorption of class C hollow concrete block compared to the control mix with partially replaced specimen it decreases as crushed waste glass content increases and decreased by 0.55% at a 10%, 1.16% at a 20%, and 2.5% at a 30% replacement level.
3. The compressive strength of the class C hollow concrete block compared to the control mix with partially replaced specimen it increases up to 20% replacement by 59.72% but after that, it starts decreasing for 30% replacement by 10.64%.
4. The results of class hollow concrete block mixes produced by partially replacing fine aggregate with crushed waste glass up to 20% are within the acceptable range of minimum compressive strength as per the Ethiopia standard. the optimum percentage replacement of crushed waste glass is up to 20% by volume which provides maximum compressive strength at 28day is 3.45 MPa increased by 59.72% as compared to the control mix. but after that, it starts decreasing at 28day for 30% replacement 1.93 MPa compared to the control mix it decreases by 10.64%.
5. The production cost per block for class C hollow concrete block using 20% crushed waste glass saves costs by 2.06% in $1m^2$ area compared to the conventional once.

5.2 Recommendation

Underlisted are some recommendations as a result of this research:

1. Crushed waste glass can replace fine aggregate up to 20% by volume in class C hollow concrete block for it is preferable compared to the conventional block with regard to density, water absorption, and compressive strength, and also the production cost. Therefore, the concrete production firms can incorporate 20% of crushed waste glass as fine aggregate in class C hollow concrete block.
2. The concerned government bodies shall set directives on waste glasses and the concrete block production firms focus on the means of collecting crushed waste glass and utilizing it for concrete block purposes.
3. A lot of researches have been conducted on different waste materials which are used to partially replace concrete making ingredients. However, most of them are on the shelf, and the trend to apply to the construction industry is too low due to awareness and other challenges. Therefore, in Hawassa university research centers should be established which focus on the study of wastes that can be reuse and used as alternative concrete making materials.
4. In this research, only density, water absorption and compressive strength using crushed waste glass in hollow concrete block production are investigated; therefore, a further study which should be continued as part of the extension of this study are listed as follows:
   A. The long-term effects of class C hollow concrete block produced by partial replacement of fine aggregate with crushed glass.
   B. Alkali is the main components of cement while silica is for glass. Therefore, there is a probability of reaction between the two through time. The effect of alkali-silica reaction is not included in this study.
   C. Further study should be carried out on the performance of class C HCB between 21-29% replacement level of crushed waste glass as fine aggregate.
   D. The collection and crushing method of glass needs caution with respect to safety and health. study is needed on safe way of using glasses in HCB.

REFERENCE

Abebe Dinku. 2002. Construction Materials Laboratory Manual. In Addis Ababa University Printing Press.

Abera Mikiyas. 2019. Investigating the acceptable quantity of fine aggregate to be replaced with sawdust to obtain strong , light weight , and economical result for HCB production (Vol. 5, Issue 5).

Adaway M., & Wang Y. 2015. Recycled glass as a partial replacement for fine aggregate in structural concrete -Effects on compressive strength. Electronic Journal of Structural Engineering, 14(1), 116–122.

Ahamed Sajad. 2013. Study of Concrete Involving Use of Waste Glass as Partial Replacement of Fine Aggregates. IOSR Journal of Engineering (IOSRJEN), 3(7), 8–13.

Akhnoukh Amin. K., Kamel Lois. Z., & Barsoum Magued. M. 2016. Alkali Silica Reaction Mitigation and Prevention Measures for Arkansas Local Aggregates. World Academy of Science, Engineering and Technology, 10(2), 95–99.

American Society for Testing and Materials (ASTM C90-70). Concrete Masonry Units.

American Society for Testing and Materials (ASTM C129-70). Hollow non-load bearing Concrete Masonry Units.

American Society for Testing and Materials (ASTM C33). Standard Specification for Concrete Aggregates.

American Society for Testing and Materials (ASTM C136-93). Sieve analysis of fine and Coarse Aggregates.

British Standard (BS 882:1992). Specification for aggregates from natural sources.

Carless Jennifer. 1992. Taking Out the Trash: A No-Nonsense Guide to Recycling, Washington, DC: Island Press.

Chen, Z., Li, J. S., & Poon, C. S. 2018. Combined use of sewage sludge ash and recycled glass cullet for the production of concrete blocks. Journal of Cleaner Production, 171(January 2018), 1447–1459.

Denamo Addissie. 2005. Handling of Concrete Making Materials in The Ethiopian Construction Industry. Addis Ababa University, Ethiopia.

Disfani M. M., Arulrajah, A., Bo, M. W., & Sivakugan, N. 2012. Environmental risks of using recycled crushed glass in road applications. Journal of Cleaner Production, 20(1), 170–179.

Du, Hongjian., & Tan, Kiang. H. 2014. Waste glass powder as cement replacement in concrete. Journal of Advanced Concrete Technology, 12(11), 468–477.

Ethiopia Ministry of Environment and Forest. 2016. Facilitating Implementation and Readiness for Mitigation (FIRM).

Ethiopian Ministry of Federal affairs. 2006. GTZ Low-Cost Housing Technical Manual Volume I.

Ethiopian standard (ES 596:2001). 2012. Specification For Concrete Masonry Units, Published By Ethiopian Standard Agency.

Gautam, Vikas Srivastava. and Agarwal. V.C. 2012. Use of glass wastes as fine aggregate in Concrete. J. Acad. Indus. Res., 1(6)(May 25-28), 320–322.

Global Shelter Cluster. 2014. Hollow Blocks Concrete. Humanitarian Shelter Working Group, 1–3.

Indian Standard IS 6061 (part I) 1971: Code of Practice for Construction of Floor and Roof . with Joists and Filler blocks.

Indian standard IS: 2185 (Part I). 1979. Specification for Concrete Masonry units.

Km Aswathy., Prathibha V., Issac Rinu., & Jacob Rose. R.. 2015. Decorative Concrete Using Recycled Glass Aggregate. International Journal of Civil and Structural Engineering Research ISSN, 2(2), 166–171.

Ling, T., Poon, C., Hom, H., & Kingdom, U. 2014. Effects of Recycled Fine Glass Aggregates on the Properties of Dry-Mixed Concrete Blocks Gerry. Construction and Building Material, 209–215.

Mahlet Desalegn. 2019. Textile Industry Sludge Utilization for The Production of Concrete Block Using A Bio Enzyme. Addis Ababa, Ethiopia.

Medina, C., Sánchez De Rojas, M. I., & Frías, M. 2012. Reuse of sanitary ceramic wastes as coarse aggregate in eco-efficient concretes. Cement and Concrete Composites, 34(1), 48–54.

Meng Yazi., Ling Tung. C, & Mo Kim. H. 2018. Recycling of wastes for value-added applications in concrete blocks: An overview. Resources, Conservation and Recycling, 138(May), 298–312.

Michael Geschke. 2012. Hollow concrete block production and Quality Management. Addis Abeba: GIZ University capacity building program.

Nishikant, K., Nachiket, A., Avadhut, I., & Sangar, A. 2016. Manufacturing of Concrete Paving Block by Using Waste Glass Material. International Journal of Scientific and Research Publications, 6(6), 61–77.

Osuji, S., & Egbon, B. 2015. Optimizing Compressive Strength Characteristics of Hollow Building Blocks from Granite Quarry Dust and Sand. Nigerian Journal of Technology, 34(3), 478.

Otunyo, A. W., & Okechukwu, B. N. 2017. Performance of concrete with partial replacement of fine aggregates with crushed waste glass. Nigerian Journal of Technology, 36(2), 403.

Portland Cement Association Durability Subcommittee. 2011. Evaluation of Alkali Silica Reactivity Mortar Bar Testing (ASTM C1260 and C1567), Washington DC.

Sekhar Vijaya. R., Sumalatha, P., Madhuri, M., & Ashalatha, K. 2015. Incorporation of Waste Glass Powder as Partial Replacement of Fine Aggregate in Cement Concrete. International Journal of Scientific & Engineering Research, 6(12), 405–409.

Srivastava Ishan, Gupta Dushyant, Sehmi Singh. S, Shivam Kumar, & Bharadwaj Jhalki. 2009. Partial Replacement of Fine Aggregates with Waste Glass. 3, 746–749.

Topcu Ilker. B., and Sengel Selim. 2004. Properties of concretes produced with waste concrete aggregate. Cement and Concrete Research, 34(8), 1307–1312.

Turgut, P., & Yahlizade, E. S. 2009. Research into Concrete Blocks with Waste Glass. International Journal of Civil and Environmental Engineering, 1(4), 203–209.

Umar, U. A., Shafiq, N., MalakSajad, A., Nuruddin, M. F., & Khamidi, M. F. 2017. A review on adoption of novel techniques in construction waste management and policy. In Journal of Material Cycles and Waste Management.

APPENDIX A: PROPERTIES OF MATERIAL TEST

I. Properties of fine aggregate for concrete block

- ✓ Specific gravity of fine aggregate

Weight of pycnometer = 310g, the weight of fine aggregate = 500g, Volume of pycnometer (v) =1000cm3, the volume of water added to pycnometer (Va) =806, the weight of oven dry sample in air, (A) = 490

Formula: C=09976Va + 500 +W

Where:

C = Weight of pycnometer filled with sample plus, water, [g], Va = volume of water added to pycnometer, [cm3], W = weight of pycnometer, [g]

C=0.9976 *806 + 500 + 310 = 1614g

Formula: B = 0.9976 V + W

Where:

B = Weight of flask filled with water, [g], V = Volume of flask, [cm3], W= weight of flask empty, [g]

B= 0.9976 * 1000 + 310, B = 1307.6g

$$\text{Bulk sp. gr } = \frac{A}{B + 500 - C} = \frac{490}{1307.6 + 500 - 1614} = 2.5$$

$$\text{Bulk sp. gr. (saturated surface dry) } = \frac{500}{B + 500 - C} = \frac{500}{1307.6 + 500 - 1614} = 2.58$$

$$\text{Apparente specific gtavity } = \frac{A}{B + A - c} = \frac{490}{1307.6 + 490 - 1614} = 2.66$$

$$\text{Absorption capacity (\%)} = \frac{500 - A}{A} * 100 = \frac{500 - 490}{490} * 100 = 2.04$$

II. Properties of crushed waste glass for concrete block

- ✓ Specific gravity of crushed waste glass

Weight of pycnometer = 310g, the weight of crushed waste glass = 500g, Volume of pycnometer (v) =1000cm3, the volume of water added to pycnometer (Va) = 780, The weight of oven dry sample in air, (A) = 500

Formula: C=09976Va + 500 +W

Where:

C = Weight of pycnometer filled with sample plus, water, [g], Va = volume of water added to pycnometer, [cm3], W = weight of pycnometer, [g]

C=0.9976 *806 + 500 + 310 = 1614g

Formula: B = 0.9976 V + W

Where:

B = Weight of flask filled with water, [g], V = Volume of flask, [cm3], W= weight of flask empty, [g]

B = 0.9976 V + W

B = 0.9976*780 + 310, B= 1588.12

$$\text{Bulk sp. gr} = \frac{A}{B + 500 - C} = \frac{500}{1307.6 + 500 - 1588.12} = 2.3$$

$$\text{Bulk sp. gr. (saturated surface dry)} = \frac{500}{B + 500 - C} = \frac{500}{1307.6 + 500 - 1588.12} = 2.27$$

$$\text{Apparente specific gtavity} = \frac{A}{B + A - c} = \frac{500}{1307.6 + 500 - 1588.12} = 2.27$$

$$\text{Absorption capacity (\%)} = \frac{500 - A}{A} * 100 = \frac{500 - 500}{500} * 100 = 0\%$$

APPENDIX B: THE DENSITY TEST RESULTS

i. The average density of the control mix

The average dimensions of the three control mix blocks are; 15800 cm^3

The average of weight before oven-dry [kg] = Sample A + B + C = 15.90 + 16.00 + 16.10 = 16.00

The weight after oven-dry [kg] = 15.90 + 15.90 + 15.90 = 15.90 kg

The dry density of produced block [kg/m^3]

$$\text{Sample A Densiy} = \frac{15.90 \text{ kg}}{15800\ cm3} * \frac{10^6 kg}{m3} = 1006.32$$

$$\text{Sample B Densiy} = \frac{15.90 \text{ kg}}{15800\ cm3} * \frac{10^6 kg}{m3} = 1006.32$$

$$\text{Sample C Densiy} = \frac{15.90 \text{ kg}}{15800\ cm3} * \frac{10^6 kg}{m3} = 1006.32$$

The average dry density of produced block [kg/m^3] = Sample= $\frac{A+B+C}{3}$ = 1006.32 $\underline{\underline{kg/m^3}}$

ii. The average density of 10% replacement of crushed waste glass

The average dimensions of the three control mix blocks are; 16000 cm^3

The average of weight before oven-dry [kg] = Sample A + B + C =15.90 + 16.00 + 15.80 = 15.90kg

The weight after oven-dry [kg] = Sample A + B + C = 15.70 + 15.80 + 15.60 = 15.70 kg

The dry density of produced block [kg/m^3]

$$\text{Sample A Densiy} = \frac{15.70 \text{ kg}}{16000\ cm3} * \frac{10^6 kg}{m3} = 981.25$$

$$\text{Sample B Densiy} = \frac{15.80 \text{ kg}}{16000\ cm3} * \frac{10^6 kg}{m3} = 987.50$$

$$\text{Sample C Densiy} = \frac{15.60 \text{ kg}}{16000\ cm3} * \frac{10^6 kg}{m3} = 975$$

The average dry density of produced block [kg/m3] = Sample= $\frac{A+B+C}{3}$ = $\underline{\underline{981.25\ kg/m^3}}$

iii. The average density of 20% replacement of crushed waste glass

The average dimensions of the three control mix blocks are; 16000 cm3

The average of weight before oven-dry [kg] = Sample A + B + C =15.90 + 15.80 + 15.70 = 15.80kg

The weight after oven-dry [kg] = Sample A + B + C = 15.60 + 15.40 + 15.50 = 15.50 kg

The dry density of produced block [kg/m3]

$$\text{Sample A Densiy} = \frac{15.60\ \text{kg}}{16000\ cm3} * \frac{10^6 kg}{m3} = 975$$

$$\text{Sample B Densiy} = \frac{15.40\ \text{kg}}{16000\ cm3} * \frac{10^6 kg}{m3} = 962.50$$

$$\text{Sample C Densiy} = \frac{15.50\ \text{kg}}{16000\ cm3} * \frac{10^6 kg}{m3} = 968.75$$

The average dry density of produced block [kg/m3] = Sample= $\frac{\text{A+B+C}}{3}$ = 968.75 kg/m^3

iv. The average density of 30% replacement of crushed waste glass

The average dimensions of the three control mix blocks are; 16000 cm3

The average of weight before oven-dry [kg] = Sample A + B + C =15.60 + 15.40 + 15.50 = 15.60kg

The weight after oven-dry [kg] = Sample A + B + C = 15.10 + 15.30 + 15.20 = 15.20 kg

The dry density of produced block [kg/m3] $\text{Sample A Densiy} = \frac{15.10\ \text{kg}}{16000 cm3} * \frac{10^6 kg}{m3} = 943.75$

$$\text{Sample B Densiy} = \frac{15.30\ \text{kg}}{16000\ cm3} * \frac{10^6 kg}{m3} = 956.25, \text{Sample C Densiy} = \frac{15.20\ \text{kg}}{16000\ cm3} * \frac{10^6 kg}{m3} = 950$$

The average dry density of produced block [kg/m3] = Sample= $\frac{\text{A+B+C}}{3}$ = 950 kg/m^3

APPENDIX C: THE WATER ABSORPTION TEST RESULTS

i. The average water absorption of control mix

The average weight after removal from water and dried for one min.[kg] = Sample A + B + C

This means = 16.30 + 16.20 + 16.40 = 16.30kg

The average weight before immersed into water [kg] = Sample A + B + C

This means = 15.50 + 15.40 + 15.60 = 15.50kg

$$\text{Sample A absorption }(\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{16.30 - 15.50}{15.50} * 100 = 5.16\%$$

$$\text{Sample B absorption }(\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{16.20 - 15.40}{15.40} * 100 = 5.19\%$$

$$\text{Sample C absorption }(\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{16.40 - 15.60}{15.60} * 100 = 5.12\%$$

$$\text{The average absorption Sample }(\%) = \frac{\text{A+B+C}}{3} = \frac{5.16 + 5.19 + 5.12}{3} = 5.16\%$$

ii. The average water absorption of 10% replacement mix

The average weight after removal from water and dried for one min.[kg] = Sample A + B + C

This means = 15.80 + 15.90 + 16.00= 15.90 kg

The average weight before immersed into water [kg] = Sample A + B + C

This means = 15.10 + 15.20 + 15.30= 15.20 kg

$$\text{Sample A absorption }(\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{15.80 - 15.10}{15.10} * 100 = 4.63\%$$

$$\text{Sample B absorption }(\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{15.90 - 15.20}{15.20} * 100 = 4.60\%$$

$$\text{Sample C absorption }(\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{16.00 - 15.30}{15.30} * 100 = 4.57\%$$

$$\text{The average absorption Sample }(\%) = \frac{\text{A+B+C}}{3} = \frac{4.63 + 4.60 + 4.57}{3} = 4.61\%$$

iii. The average water absorption of 20% replacement mix

The average weight after removal from water and dried for one min.[kg] = Sample A + B + C

This means = 15.50 + 15.70 + 15.60= 15.60 kg

The average weight before immersed into water [kg] = Sample A + B + C

This means = 15.00 + 15.00 + 15.00= 15.00 kg

$$\text{Sample A absorption } (\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{15.50 - 15.00}{15.00} * 100 = 3.33\%$$

$$\text{Sample B absorption } (\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{15.70 - 15.00}{15.00} * 100 = 4.66\%$$

$$\text{Sample C absorption } (\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{15.60 - 15.00}{15.00} * 100 = 4.00\%$$

The average absorption Sample $(\%) = \frac{\text{A+B+C}}{3} = \frac{3.33 + 4.66 + 4.00}{3} = 4.00\%$

iv. The average water absorption of 30% replacement mix

The average weight after removal from water and dried for one min.[kg] = Sample A + B + C

This means = 15.50 + 15.30 + 15.40 = 15.40 kg

The average weight before immersed into water [kg] = Sample A + B + C

This means = 15.10 + 15.00 + 14.90 = 15.00 kg

$$\text{Sample A absorption } (\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{15.50 - 15.10}{15.10} * 100 = 3.33\%$$

$$\text{Sample B absorption } (\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{15.30 - 15.00}{15.00} * 100 = 2.00\%$$

$$\text{Sample C absorption } (\%) = \frac{\text{A} - \text{B}}{\text{B}} * 100 = \frac{15.40 - 14.90}{14.90} * 100 = 2.66\%$$

The average absorption Sample $(\%) = \frac{\text{A+B+C}}{3} = \frac{3.33 + 2 + 2.66}{3} = 2.66\%$

APPENDIX D: THE COMPRESSIVE STRENGTH TEST RESULTS

Table Appendix D 1 The compressive strength at 7day of 0% class C HCB

Sample	Dimension (cm2)			Area(cm2)	Failure load (KN)	Compressive strength (MPa)
0%	L	W	H			
1	40	20	20	408	40.2	0.98
2	40	20	20	408	37.6	0.92
3	40	20	20	408	42.6	1.04
4	40	20	20	408	39	0.95
5	40	20	20	408	41.3	1.01
6	40	20	20	408	38	0.93
Total						5.83
Mean						0.97

Table Appendix D 2 The compressive strength at 7day of 10% CWG class C HCB

Sample	Dimension (cm2)			Area(cm2)	Failure load (KN)	Compressive strength (MPa)
10%	L	W	H			
1	40	20	20	408	44	1.07
2	40	20	20	408	47.5	1.16
3	40	20	20	408	57.3	1.4
4	40	20	20	408	60.1	1.47
5	40	20	20	408	42.8	1.04
6	40	20	20	408	55.8	1.36
Total						7.5
Mean						1.25

Table Appendix D 3 The compressive strength at 7day of 20% CWG class C HCB

Sample	**Dimension (cm2)**				**Failure load (KN)**	**Compressive strength (MPa)**
20%	**L**	**W**	**H**	**Area(cm2)**		
1	40	20	20	408	60.1	1.47
2	40	20	20	408	52.8	1.29
3	40	20	20	408	52.4	1.28
4	40	20	20	408	50	1.22
5	40	20	20	408	49.5	1.21
6	40	20	20	408	48.5	1.18
Total						7.65
Mean						1.28

Table Appendix D 4 The compressive strength at 7day of 30% CWG class C HCB

Sample	**Dimension (cm2)**			**Area(cm2)**	**Failure load (KN)**	**Compressive strength (MPa)**
30%	**L**	**W**	**H**			
1	40	20	20	408	48.5	1.18
2	40	20	20	408	47.7	1.16
3	40	20	20	408	47.7	1.16
4	40	20	20	408	44.5	1.09
5	40	20	20	408	43.6	1.06
6	40	20	20	408	39.8	0.97
Total						6.62
Mean						1.11

Table Appendix D 5 The compressive strength at 14day of 0% CWG class C HCB

Sample	**Dimension (cm2)**			**Area(cm2)**	**Failure load (KN)**	**Compressive strength (MPa)**
0%	**L**	**W**	**H**			
1	40	20	20	408	76.6	1.87
2	40	20	20	408	73.6	1.8
3	40	20	20	408	67.8	1.66
4	40	20	20	408	78.9	1.93
5	40	20	20	408	47.8	1.17
6	40	20	20	408	68.7	1.68
Total						10.11
Mean						1.68

Table Appendix D 6 The compressive strength at 14day of 10% CWG class C HCB

Sample	**Dimension (cm2)**			**Area(cm2)**	**Failure load (KN)**	**Compressive strength (MPa)**
10%	**L**	**W**	**H**			
1	40	20	20	408	88.5	2.16
2	40	20	20	408	94.8	2.32
3	40	20	20	408	92.9	2.27
4	40	20	20	408	87.7	2.14
5	40	20	20	408	78.2	1.81
6	40	20	20	408	91.4	2.24
Total						12.94
Mean						2.15

Table Appendix D 7 The compressive strength at 14day of 20% CWG class C HCB

Sample	**Dimension (cm2)**			**Area(cm2)**	**Failure load (KN)**	**Compressive strength (MPa)**
20%	**L**	**W**	**H**			
1	40	20	20	408	105.4	2.58
2	40	20	20	408	96.7	2.37
3	40	20	20	408	99.2	2.43
4	40	20	20	408	109.3	2.67
5	40	20	20	408	93.6	2.29
6	40	20	20	408	100.8	2.47
Total						14.81
Mean						2.46

Table Appendix D 8 The compressive strength at 14day of 30% CWG class C HCB

Sample	**Dimension (cm2)**			**Area(cm2)**	**Failure load (KN)**	**Compressive strength (MPa)**
30%	**L**	**W**	**H**			
1	40	20	20	408	61.5	1.5
2	40	20	20	408	68.6	1.68
3	40	20	20	408	56.7	1.38
4	40	20	20	408	70.9	1.73
5	40	20	20	408	68.8	1.68
6	40	20	20	408	58.1	1.42
Total						9.39
Mean						1.56

Table Appendix D 9 The compressive strength at 28day of 0% CWG class C HCB

Sample	**Dimension (cm2)**			**Area(cm2)**	**Failure load (KN)**	**Compressive strength (MPa)**
0%	**L**	**W**	**H**			
1	40	20	20	408	94.1	2.3
2	40	20	20	408	98.6	2.41
3	40	20	20	408	77.3	1.89
4	40	20	20	408	93.8	2.29
5	40	20	20	408	79.7	1.95
6	40	20	20	408	86.5	2.12
Total						12.96
Mean						2.16

Table Appendix D 10 The compressive strength at 28day of 10% CWG class C HCB

Sample	**Dimension (cm2)**			**Area(cm2)**	**Failure load (KN)**	**Compressive strength (MPa)**
10%	**L**	**W**	**H**			
1	40	20	20	408	98.2	2.4
2	40	20	20	408	125.2	3.06
3	40	20	20	408	83.6	2.04
4	40	20	20	408	112.7	2.76
5	40	20	20	408	131.7	3.22
6	40	20	20	408	90.7	2.33
Total						15.81
Mean						2.63

Table Appendix D 11 The compressive strength at 28day of 20% CWG class C HCB

Sample	**Dimension (cm2)**			**Area(cm2)**	**Failure load (KN)**	**Compressive strength (MPa)**
20%	**L**	**W**	**H**			
1	40	20	20	408	156.8	3.84
2	40	20	20	408	116.2	2.84
3	40	20	20	408	115.5	2.83
4	40	20	20	408	156.9	3.84
5	40	20	20	408	145.5	3.56
6	40	20	20	408	154.4	3.78
Total						20.69
Mean						3.45

Table Appendix D 12 The compressive strength at 28day of 30% CWG class C HCB

Sample	**Dimension (cm2)**			**Area(cm2)**	**Failure load (KN)**	**Compressive strength (MPa)**
30%	**L**	**W**	**H**			
1	40	20	20	408	100.9	2.47
2	40	20	20	408	66.6	1.63
3	40	20	20	408	76.8	1.88
4	40	20	20	408	80.1	1.96
5	40	20	20	408	77.8	1.9
6	40	20	20	408	72.5	1.77
Total						11.61
Mean						1.93

APPENDIX E: COST COMPARISONS

Table Appendix E 1 Cost comparisons

No	Description	Amount
1	Ratio of HCB	1:4:2 (Cement, Sand &00 gravel respectively)
2	Cement bags cost (50kg)	175birr
3	Optimum sand replacement by waste glass	20%
4	No HCB produced per unit cement bag	30
5	No of HCB per unit m^2 of wall area	12.5
6	weight of Conventional HCB	16.3kg
7	Weight of HCB with 20% replacement	15kg
8	weight of cement for $1m^2$ HCB wall area	20.84kg
9	cost of 20.84 kg of cement	62.5
10	weight of sand per unit m^2 HCB wall area kg (with replacement)	85.5
11	weight of sand per unit m^2 HCB wall area kg (Conventional)	116.1375
12	bulk specific gravity of sand	2.5
13	weight of sand per unit m^3	2400 kg/m^3
14	Cost of one Sino truck sand ($16m^3$)	5000birr
15	weight of one Sino truck sand	38400 kg
16	cost of sand per unit m^2 HCB wall area (with replacement)	10.71 birr
17	cost of sand per unit m^2 HCB wall area (Conventional)	15.12birr
18	cost of 00 gravel per unit m^2 of HCB wall area	6.1birr

APPENDIX F: CHEMICAL COMPOSITION TEST RESULTS OF CWG

Table appendix F 1: Complete silicate analysis of crushed waste glass report

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

Issue Date: -04/02/2020

Customer Name:- Yosef Kuma.

Request No:- GLD/RQ/050/20

Report No:- GLD/RN/47/20

Sample type:- Glass

Sample Preparation: - 200 Mesh

Date Submitted: - 16/01/2020

Number of Sample:- One (1)

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

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
Y-k-01	71.66	<0.01	0.28	10.34	3.76	14.18	0.52	0.04	0.05	0.03	0.08	0.25

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

Analysts	Checked By	Approved By	Quality Control
Yirgalem Abriham			
Tizita Zemene			
Nigist Fikadu	for Yohannes Getachew	Gosa Haile	Negash Worku

APPENDIX G: SAMPLE PHOTOS TAKEN DURING THE RESEARCH

Glass collected from waste dumping area

Manually crushed waste glasses

The crushed glass glasss sieved by ASTM 4.75mm into fine aggregate sizes

Measuring the volume of box and add the required percentages of CWG replacement


Mixing the crushed waste glass with conceret block making materials


The crushed waste glass preparation mix for 10%, 20%, and 30% replacements


The crushed waste glass mixing for 10%, 20%, and 30% replacements


The operator making block to the size of 20*20*40 cm through manual machine


The produced hollow concrete blocks size 20*20*40 cm

The produced hollow concrete blocks size 20*20*40 cm for 0,10,20, and 30% replacements

Making the block contact surfaces, with the testing machine, of each sample capping with 1:1 mortar of 2 to 3mm thickness.

Load the block from the production site to SNNPS construction Authority construction material laboratory test

The compressive strength test machine and result